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Atmospheric conditions controlling extreme summertime evapotranspiration in Poland (central Europe)

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Abstract Extremely high evapotranspiration may constitute a threat to agriculture and to water storage, supply, management and quality. To better understand the occurrence of high evapotranspiration, our goals were to (1) document the synoptic conditions favorable for extreme evapotranspiration and (2) determine the anomalies in the factors that directly affect extremely high evapotranspiration on a daily scale. We calculated the daily reference evapotranspiration (ET_0; June–August, 1971–2010) for 31 stations in Poland using the FAO-56 Penman–Monteith method and identified the days with the highest ET_0 values (>90th percentile). For these days, we calculated the sea level pressure (SLP), the 500 hPa geopotential heights ($z500$), the air temperature at 850 hPa ($t850$) and the amount of precipitable water. We detected a correlation between the air pressure field and high ET_0 values ($r > 0.4$, $p < 0.001$) in northeast Poland; positive anomalies in SLP, $z500$ and $t850$ were documented on days with high ET_0. Substantial anomalies were also observed in the factors that directly affect evapotranspiration, i.e., sunshine duration and air temperature (positive) and relative humidity (negative). The conditions favorable for high ET_0 events are characteristic of anticyclonic weather, so when an anticyclone center is near northeast Poland, high evapotranspiration can be expected.

Keywords Extreme evapotranspiration · Penman–Monteith method · Synoptic patterns · Central Europe

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1 Introduction

In the future, the intensity and variability of the hydrological cycle are predicted to increase, and extreme phenomena, such as floods and droughts, are likely to become more common (IPCC 2007). These extremes frequently pose economic threats, so it is essential that we further our knowledge of the entire hydrological cycle (Bosilovich and Schubert 2002). Evapotranspiration, which is defined as evaporation from the soil and transpiration from plants, is a crucial component of the hydrological cycle that may be used as a sensitive indicator of changes in the intensity of the cycle (Huntington 2006). Evapotranspiration is also one of the most important hydrological parameters for planning and managing water resources, particularly for scheduling irrigation in agriculture, so extreme evapotranspiration values (along with low precipitation) are a critical consideration from a food security perspective (Mishra and Singh 2010). Moreover, evapotranspiration is included in all hydrological water balance models and is a popular topic in many international research programs, such as the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Program on Global Environmental Change (Liang et al. 2008; Tabari and Talaee 2014).

The intensity of evapotranspiration is controlled by numerous meteorological factors, including solar radiation, air temperature, humidity and wind speed (i.e., Goyal 2004; Tabari and Talaee 2014), and the importance of these parameters to the variability in evapotranspiration has been repeatedly emphasized in the literature (e.g., Gong et al. 2006; Liang et al. 2008; Estevez et al. 2009). However, all of these individual meteorological and hydrometeorological parameters, including evapotranspiration, are affected by atmospheric circulation, i.e., the large-scale movement of air masses in the atmosphere. The impact of atmospheric circulation on different meteorological elements has been thoroughly studied in relation to, for example, air temperature (Xoplaki et al. 2003), precipitation (Jacobeit et al. 2009), fog (Houssos et al. 2012), snow cover and melt (Bednorz 2011), and hail (Suwała 2013). However, information about the influence of atmospheric circulation on pan evaporation and evapotranspiration remains scarce (Jalili et al. 2012).

We assume that particular pressure fields and circulation patterns over the Euro-Atlantic sector of the Northern Hemisphere result in conditions that are conducive to extreme evaporation in Poland. Furthermore, high evapotranspiration is associated with anomalies in particular meteorological variables, such as sunshine duration and the air temperature, humidity and water content in the atmosphere. Our main objective in this study is to describe the atmospheric conditions that promote extreme evapotranspiration values in Poland in the summer, namely the macroscale pressure, circulation patterns and other synoptic conditions on days with extreme evapotranspiration. The ability to predict evapotranspiration is especially important in water management as it strongly influences the supply of water for agriculture. Under the climatic conditions of Poland, where water shortages due to drought often occur during the warm season (Bonaccorso et al. 2013), predicting extreme evapotranspiration events is crucial, and such forecasts may be enhanced by understanding the atmospheric conditions that cause such events and which are examined in this study.

2 Materials and methods
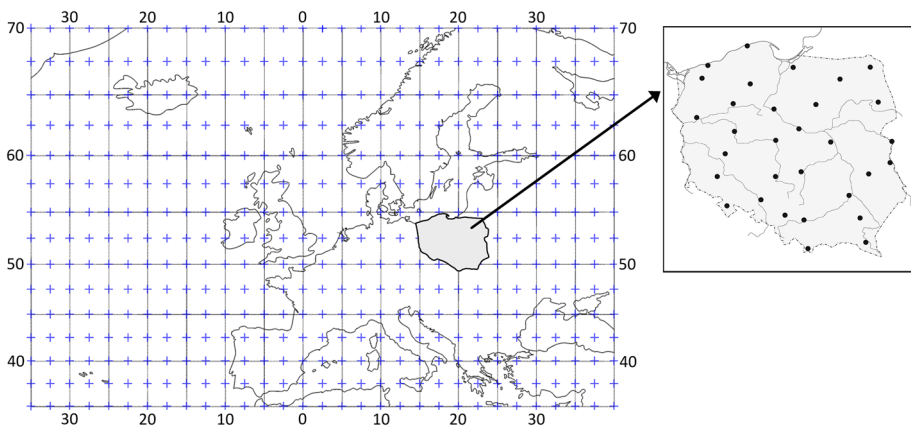
2.1 Evapotranspiration model

The evapotranspiration model used in this study requires standard meteorological data, which were obtained from the Polish Institute of Meteorology and Water Management. Daily data from 31 operational meteorological stations in Poland for the summers (June–August) of 1971–2010 were employed to calculate evapotranspiration values using the model described below (Fig. 1; Table 1). A small part of the dataset was missing, especially from the beginning of the study period, and the numbers of days with data gaps are shown in Table 1. All of the data gaps were addressed using data from adjacent stations.

The Penman–Monteith FAO-56 (PMF56) method, which was developed and modified by experts from the International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organization of the United Nations (FAO) (Allen et al. 1998), is the most commonly used method for determining reference evapotranspiration (ET_0). The method is considered to be the standard, and it produces the most precise results when applied to various climates around the world (e.g., Trajkovic et al. 2003; Garcia et al. 2004; Sabziparvar et al. 2010; Sentelhas et al. 2010; Tabari et al. 2013). This method requires non-standard meteorological data, such as net or solar radiation, that may only be recorded at select stations, so the data are commonly unavailable. To overcome this limitation, Allen et al. (1998) proposed a set of procedures for sparse data, such as using sunshine duration as a proxy for solar radiation. These procedures, which have been calibrated for conditions in Poland, were applied in this study to calculate the daily ET_0, i.e., the evapotranspiration from well-watered, actively growing grass with a height of 0.12 m, a surface resistance of 70 Sm and an albedo of 0.23 (Allen et al. 1998).

The reference evapotranspiration was calculated with the PMF56 method as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u(e_s - e_a)}{\Delta + \gamma(1 + 0.34u)}, \tag{1}$$

where ET_0 is the reference crop evapotranspiration (mm day^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), which is null for daily periods, T_a

Fig. 1 The area represented by the SLP and *z500* data with marked grid points and the locations of the meteorological stations used in the study

Table 1 Description of the surface data series used to calculate reference evapotranspiration and synoptic variables used in the study

Used surface/macroscale data series	Abbreviation	Unit	Lacking data
Reference evapotranspiration	ET_0	mm	–
Sunshine duration	n (or) SH	h	25,977 (5.7 %)
Mean air temperature at 2 m a.s.l.	T_a	°C	2
Maximum air temperature at 2 m a.s.l.	T_{max}	°C	3
Minimum air temperature at 2 m a.s.l.	T_{min}	°C	3
Precipitation	P	mm	1
Relative humidity	RH	%	6
Wind speed (2 m; converted from 10 m)	u	m s^{-1}	703 (0.15 %)
Sea level pressure	SLP	hPa	–
500 hPa geopotential height	$z500$	M	–
Mean air temperature at 850 hPa geopotential height	$t850$	°C	–
Precipitable water	PW	kg m^{-2}	–

is the average daily air temperature at a height of 2 m (°C), u is the wind speed at a height of 2 m (m s^{-1}), e_s is the saturation vapor pressure [kPa], e_a is the actual vapor pressure (kPa), $e_s - e_a$ is the vapor pressure deficit (kPa), Δ is the slope of the saturation vapor pressure–temperature curve (kPa °C^{-1}) and γ is the psychrometric constant (kPa °C^{-1}).

Net and solar radiation data were lacking for almost all of the meteorological stations, so we used the procedures for estimating these two variables originally described by Allen et al. (1998). They are based on the Ångström equation (used to calculate solar radiation), which is recommended to be calibrated for local conditions (Allen et al. 1998). Therefore, we used the Ångström equation calibrated for conditions in Poland as follows (Bogawski and Bednorz 2014):

$$R_s = \left(0.094 + 0.549\frac{n}{N}\right)R_a, \tag{2}$$

where the n/N ratio represents the relative sunshine duration (dimensionless) and R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}) for a particular location and day of the year.

2.2 Extreme ET_0 values

Extreme summertime evapotranspiration values were determined according to the rules of the Intergovernmental Panel on Climate Change, for which the frequency is less than or equal to 10 % (IPCC 2007). Therefore, the mean daily reference evapotranspiration values that were equal to or exceeded the 90th percentile in summer at a particular station were considered positive extremes in this station. The days when evapotranspiration exceeded the given threshold in at least half (16) of the stations in Poland were selected for further synoptic analysis, which is described in Sect. 2.3.

To determine the background conditions for the detailed analysis of the atmospheric conditions controlling extremely high evapotranspiration in Poland, we analyzed simple linear trends between the mean daily reference evapotranspiration and other

meteorological parameters ($T_{\max}$, $T_{\min}$, SH, RH, P) from 1971 to 2010. The data from all of the stations were averaged to calculate these trends.

2.3 Atmospheric circulation

To relate the occurrence of evapotranspiration extremes to synoptic conditions, the "environment-to-circulation" approach was applied. In this method, the circulation is classified according to a specific set of environmental criteria for a particular phenomenon, i.e., the evapotranspiration extremes addressed in this study (Yarnal 1993; Dayan et al. 2012). To identify the macroscale pressure patterns and circulation conditions that promote positive ET_0 extremes, the mean daily sea level pressure (SLP) and 500 hPa geopotential heights (z500) were used (Table 1). These reanalysis data were obtained from the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) (Kalnay et al. 1996). Other mesoscale meteorological conditions on the days with positive ET_0 extremes were identified using air temperature at the 850 hPa level (t850) and precipitable water (PW) data from the same source. The 850 hPa level is approximately 1500 m above the atmospheric boundary layer. At this height, the underlying surface does not affect the temperature, so t850 is often used to distinguish cold and warm air masses, which are only affected by air circulation. The PW index represents the mass of water contained in a column of air above a unit surface area (kg m^{-2}) regardless of the state of aggregation (Wibig and Siedlecki 2007). The resolution of all of the NCEP/NCAR reanalysis data used in the study is $2.5° \times 2.5°$, and area represented by the SLP and z500 data with marked grid points is shown in Fig. 1.

First, the Pearson's correlation coefficients (r) between the daily reference evapotranspiration averaged for the 31 stations and the daily SLP values at the grid points within 35°–70°N and 35°W–40°E (Fig. 1) were calculated and mapped. Because of the large number of data points ($n = 3680$), very low values of r were statistically significant ($|r| = 0.055$ is statistically significant at $p = 0.001$). Furthermore, composite maps of the SLP and z500 means and anomalies were constructed for the days with extreme ET_0 values, which were observed at more than half of the stations considered in the analysis (at least 16 stations). Additionally, t850 and PW anomaly maps were constructed, and the anomalies were computed as the differences between the composite values and the 40-year summer means (June–August). All of the contour maps included in Sect. 3 were produced using Kriging with a simple linear variogram model, which is one of the most popular geostatistical gridding methods used for interpolation.

Air circulation is considered to be one of the most important factors determining weather conditions because it transports distinct air masses from various source regions. To detect the source areas of the air masses that cause extremely high evaporation in Poland, 3-day backward trajectories of air particles were constructed for select days with extreme ET_0 using the NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Rolph 2012; Draxler and Rolph 2012). HYSPLIT is a commonly used trajectory model developed by the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory (ARL). HYSPLIT uses archived three-dimensional meteorological fields generated from observations and short-term forecasts, and it can be run to generate forward or backward trajectories using several available meteorological data archives. Back trajectory analyses use interpolated or modeled meteorological fields to estimate the most likely paths over geographical areas that provide air to a destination area at a given time. Essentially, the method follows a parcel of air backward in hourly steps for a specified length of time. The backward trajectories were computed with the NCEP/NCAR

reanalysis data available from the ARL. The analysis of the air trajectories substantially added to the information obtained from the synoptic maps and made it possible to identify the direction of air flows on the days with extreme evapotranspiration.

Finally, anomaly maps of the main meteorological variables, such as ET_0, T_{max}, SH and RH, were constructed for the days with extreme ET_0 in at least 16 stations (see the explanations in Sect. 2.2). Anomalies were computed as the differences between the composite values and the 40-year summer means (June–August).

3 Results

3.1 Mean and extreme reference evapotranspiration values in summer

The mean evapotranspiration values for summer were highest in the central part of the country and extended zonally from west to east, where they exceeded 2.9 mm (Fig. 2, left). For this study, the days with extreme ET_0 values were selected separately for each station. The values of the established 90th percentile ranged from 4.6 mm in central Poland to 3.5 in southern Poland; the spatial distribution of these values was similar to that of the mean evapotranspiration values (Fig. 2, right).

The synoptic analysis only took the days when ET_0 exceeded the 90th percentile in at least 16 stations into consideration, which amounted to 410 days (out of total number of 3680 summer days used in the analysis). Of those, 210 days occurred in July, 169 days in June and 31 days in August. Most of the extreme ET_0 days (68 %) were observed in the last two decades (1990–2010).

3.2 Multiannual changes in the selected meteorological parameters

The linear trends in the mean daily ET_0 and the associated meteorological factors were calculated (Fig. 3), and the mean daily reference evapotranspiration in summer increased
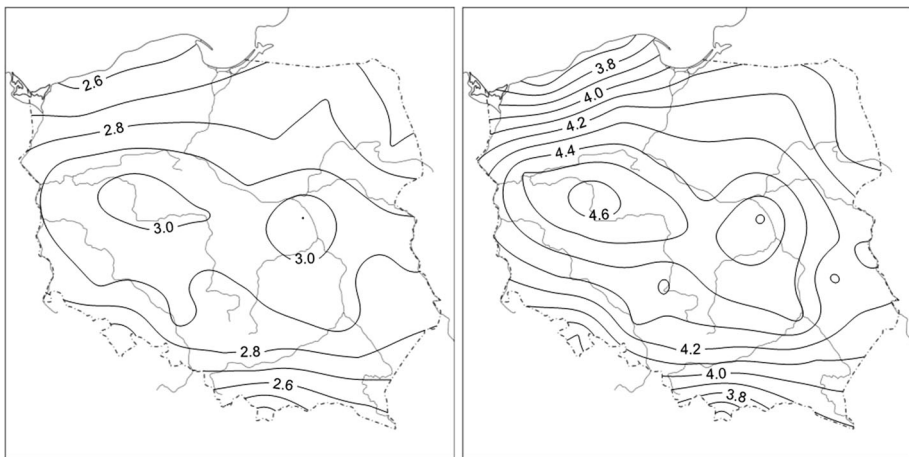
Fig. 2 Mean daily evapotranspiration ET_0 (*left*) and 90th percentile (*right*) values for the summer season (June–August) in Poland (in mm). Data for the years 1971–2010

Fig. 3 Multiannual course of the selected meteorological parameters with trend lines and equations averaged for 31 meteorological stations in Poland for summer (Jun–Aug). ET_0, reference evapotranspiration (mm); T_{max}, daily maximum temperature (°C); T_{min}, daily minimum temperature (°C); SH, sunshine hours (h); RH, relative humidity (%); P, total summer precipitation (mm)
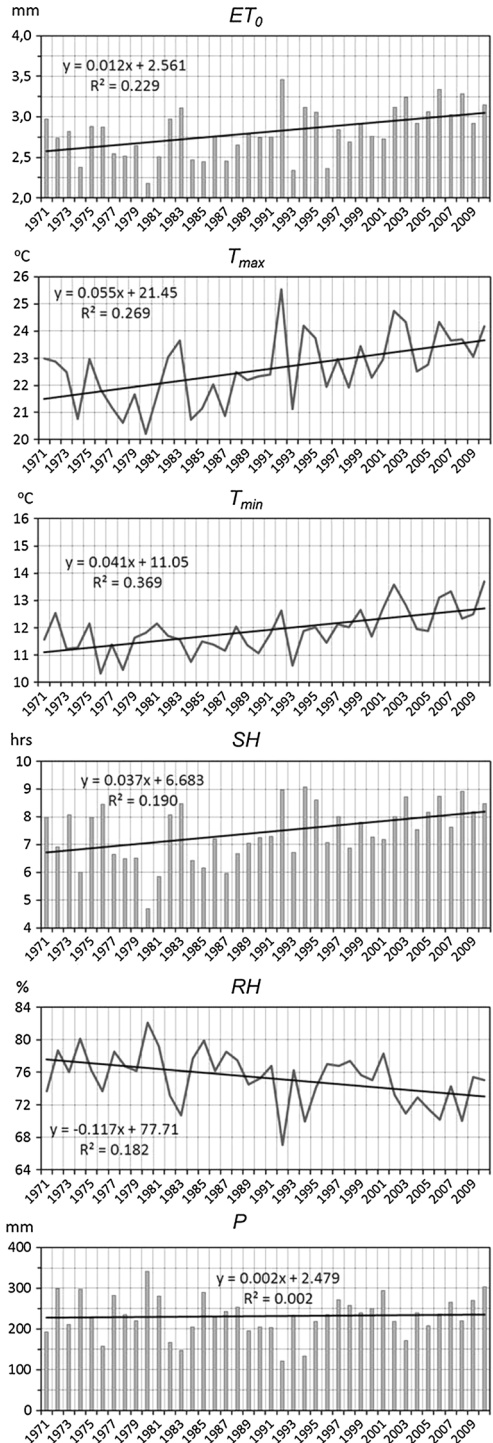
overall from 1971 to 2010 (0.12 mm/decade, $p < 0.01$). The highest evapotranspiration value was recorded in the summer of 1992 (mean daily value of 3.5 mm) and was accompanied by very low precipitation (122 mm) and long-duration mean daily sunshine (approximately 9 h). After 2002, mean daily values exceeding 3 mm occurred nearly every summer.

Statistically significant changes were also detected in the meteorological parameters that strongly influence evapotranspiration, such as the maximum daily air temperature (0.55 °C/decade; $p < 0.01$), minimum daily air temperature (0.41 °C/decade; $p < 0.01$), mean daily sunshine duration (0.37 h/decade; $p < 0.01$) and relative humidity (-1.17 %/decade; $p < 0.01$). The summer precipitation totals exhibited year-to-year variability, but the trends were not statistically significant.

3.3 Synoptic conditions on the days with extreme evapotranspiration

The mean SLP was highest (>1024 hPa) southeast of the Azores, and it gradually decreased toward the north. A low-pressure center (<1000 hPa) was located over the north Atlantic southwest of Iceland. A smaller pressure gradient was observed over eastern Europe than over the Atlantic (Fig. 4a, solid lines).

z500 is often used to study upper-level flow because it is strongly related to surface conditions. In summer, the mean *z500* declined from the southwest (5700 m over the Azores) to the north (5500 m over the northern Atlantic) (Fig. 4a, dashed lines). Such patterns cause westerly and southwesterly airflows in both the low and middle troposphere, particularly over the study area in summer.
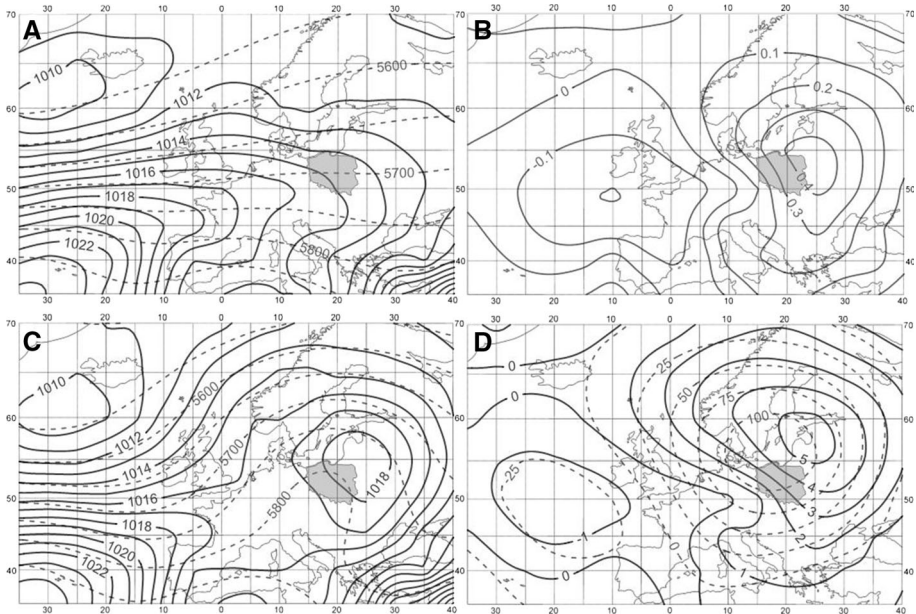
Fig. 4 Mean sea level pressure (SLP) in hPa (*solid lines*) and height of geopotential level of 500 hPa (*z500*) in gpm (*dashed lines*) in summer (**a**); the correlation coefficient between the SLP in the grid points and the ET₀ (**b**); composite map (**c**) and anomaly map (**d**) of SLP (*solid lines*) and *z500* (*dashed lines*) for the days with extreme evapotranspiration in Poland

First, to relate the occurrence of evapotranspiration extremes to synoptic conditions, the correlation coefficients between the daily reference evapotranspiration averaged for 31 stations and the daily values of the SLP at each grid point within 35°–70°N and 35°W–40°E were computed and mapped (Fig. 4b). The 0.1 and −0.1 contour lines bound the areas of statistically significant relationships ($p > 0.001$). Second, SLP and $z500$ composite and anomaly maps for the days with extreme ET_0 were constructed (Fig. 4c, d). The correlation map (Fig. 4b) shows the location of the "centers of action", namely the centers of low- and high-pressure systems' which govern the intensity of ET_0 in Poland. The correlation field indicates the strongest relationships between evapotranspiration and SLP in the eastern part of the study area, particularly northeast of Poland ($r > 0.4$), which means that high values of ET_0 in Poland are associated with high SLP values in this area and low values of ET_0 are accompanied with low-pressure systems, which locate northeast of Poland. This is also indicated in Figs. 4c and d (solid lines). The SLP in the area northeast of Poland exceeds 1018 hPa (>5 hPa anomalies) in the days of extreme ET_0, and positive anomalies in $z500$ occurred simultaneously over this anticyclone, which confirms the presence of warm air masses with low densities. An evaluation of the individual days with extreme evapotranspiration showed that the locations with the most pronounced positive SLP anomalies varied from the eastern to the northeastern parts of the study area. These pressure patterns induce an inflow of warm air masses from the eastern sector (NE, E, and SE) in the lower troposphere. Simultaneously, advection of tropical air masses from the southwest occurs in the upper troposphere (500 hPa).

The 72-h backward trajectories of the air parcels for the selected days with extreme evapotranspiration confirmed the northeastern, eastern or southeastern direction of the air flow into central Europe (Fig. 5). However, when the pressure field over Europe was indistinct, with a weak anticyclone and a small pressure gradient over the eastern part of the continent, the northward movement of the air masses was slow, as shown by the backward trajectory ending on June 7, 1998. However, the strong anticyclone indicated dynamic movement of the air, and southern Scandinavia was identified as the source region of the air masses (backward trajectory ending on July 10, 2010). Most of the trajectories showed downward movement of the air masses (from 1500–2500 m AGL to 500 m AGL), which is typical of a high-pressure system.

The described directions of the air flows caused positive anomalies in $t850$ over most of the continent; these anomalies were highest (>5 °C) over western Poland and Germany (Fig. 6a). Additionally, positive PW anomalies were observed over Western Europe (Fig. 6b). According to the Clausius–Clapeyron equation, higher than normal water content in the atmosphere is related to high temperatures, but in eastern Poland, the PW anomalies were negative due to hot but dry continental air advection from the east.

In summer, the influx of air masses from the east and southeast to central Europe caused positive ET_0 extremes as well as positive anomalies in the meteorological factors controlling ET_0 (Fig. 7). On days with extreme ET_0 (1.3–2 mm higher than the station averages), large positive T_{max} anomalies were observed that exceed 4.5 °C in most of Poland and amount to −7.5 °C in the central-western part of the country. This means that T_{max} exceeded 30 °C in western Poland on the days with positive ET_0 extremes. High values of ET_0 are also accompanied by very high values of SH, which may exceed 13.5 h in central Poland (SH anomalies >6 h). Despite the positive PW anomalies described previously and despite high vapor pressure during the days with extreme evapotranspiration, the RH is lower than the summer average (81–72 %, depending on the region) by 10 % in the most of Poland, due to the high air temperatures.
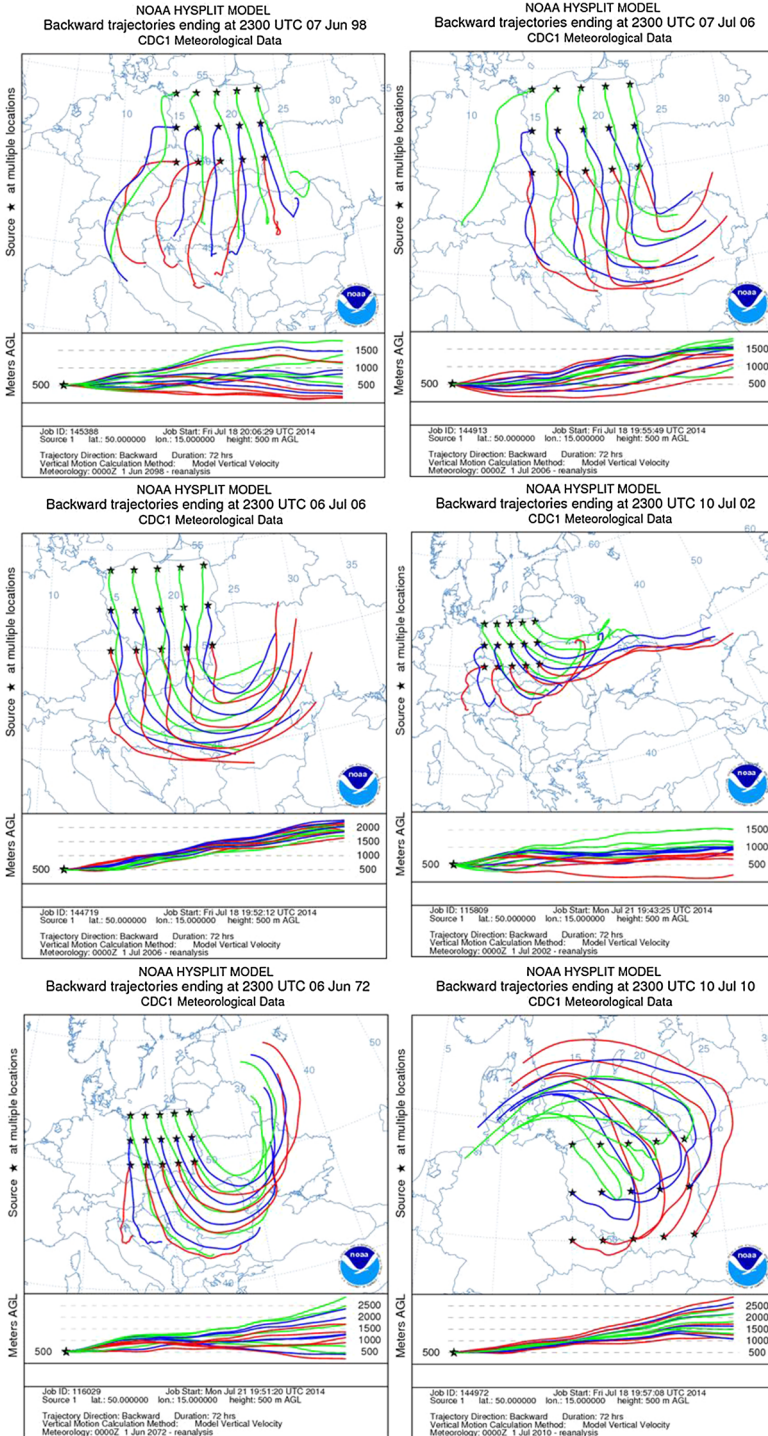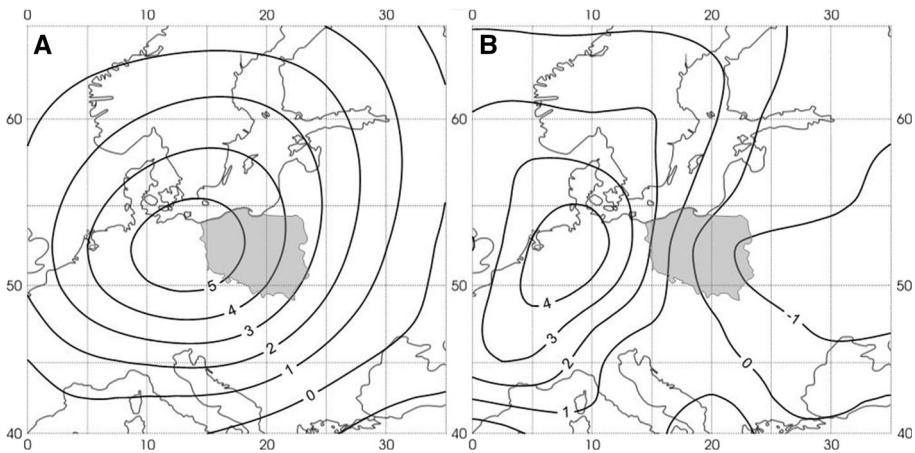
Fig. 6 Anomaly maps of air temperature at geopotential level 850 hPa (*t850*) in °C (**a**) and precipitable water (PW) in kg m^{-2} (**b**) for the days with extreme evapotranspiration in Poland

4 Discussion

The ET_0 values estimated using the Penman–Monteith FAO-56 method calibrated for Poland increased during the study period (1971–2010). This result is similar to those obtained in southern Europe, in Romania (Croitoru et al. 2013) and in Spain (Vicente-Serrano et al. 2014). Additionally, a recent study of changes in ET_0 during the growing season (April–September) in Poland found a clear increase in ET_0 (Łabędzki et al. 2014).

The ET_0 values are sensitive to changes in basic climate variables such as air temperature, humidity, solar radiation and wind speed (Gong et al. 2006; Valiantzas 2013). An increase in air temperature and solar radiation increases ET_0, whereas an increase in air humidity decreases ET_0 when other factors are unchanged (Goyal 2004). The influence of those factors depends on the climate type; ET_0 is most sensitive to sunshine hours and thus solar radiation, as well as air humidity in humid climates (Xu et al. 2006; Tabari and Talaee 2014). These findings seem to be confirmed by this study as sunshine duration increased and air humidity decreased with the increase in ET_0 in recent decades. In turn, the influence of air temperature on ET_0 in humid climates is not so distinct as in arid climates (Tabari and Talaee 2014). However, wind speed might play a dual role. High wind speed may enhance the removal of water particles from the surface of the water and thus increase ET_0, but it may also cause a decrease in the transmissivity of the atmosphere, which would limit solar radiation and thus decrease ET_0 (Goyal 2004). However, wind speed is generally considered to be a minor influence on ET_0 changes in humid climates. All of the meteorological elements mentioned are strongly influenced by air circulation, and this study identified the relevant features of the circulation patterns and synoptic conditions responsible for extreme values of ET_0 in Poland.

We found that anticyclonic pressure patterns result in the synoptic conditions associated with the highest ET_0 values. Anticyclones, i.e., high-pressure systems with clockwise descending air flow (Northern Hemisphere), may form over the Baltic Sea and to the
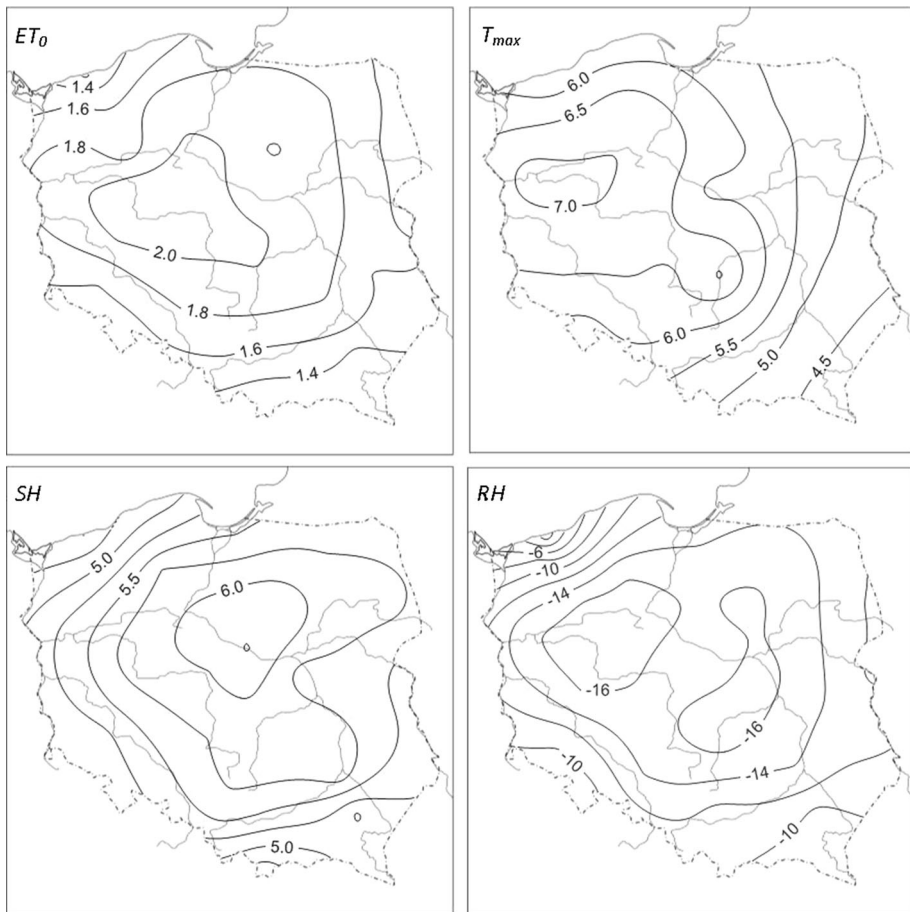
Fig. 7 Anomalies in selected meteorological parameters on the days with extreme evapotranspiration in Poland; ET_0, reference evapotranspiration (mm); T_{max}, daily maximum temperature (°C); SH, sunshine hours (h); RH, relative humidity (%)

southeast; these systems are detectable from sea level to the middle troposphere. This anticyclonic pressure pattern is associated with warm and dry continental air, clear skies, and a strong solar energy flux. An increase in solar radiation enhances the surface energy balance and increases the temperature, which leads to extreme ET_0 values.

Midlatitude summer anticyclones are known to generate extreme evapotranspiration and other extreme weather conditions, and these systems are mainly responsible for the heat waves and persistent droughts in Europe (Fink et al. 2004; Rebetez et al. 2006). For example, the importance of persistent anticyclonic conditions in the development of the 2003 heat wave over Europe was described by Black et al. (2004). Similar conditions caused the 1992 and 1994 heat waves over Prague (Kyselý 2010) and the southern coast of the Baltic Sea (Tomczyk and Bednorz 2014). According to Ustrnul et al. (2010) and Wibig (2007), the highest temperatures in Poland are associated with anticyclones without distinct advection. According to Wibig (2007), such temperatures are associated with positive anomalies in the 700 hPa geopotential level and southeasterly flow at this height, which

usually transports hot and dry air in summer. Midlatitude summer anticyclones are also associated with high solar radiation, which is related to high evapotranspiration.

A significant increase in the mean daily values of the summer ET_0 in Poland during 1971–2010 was recognized using simple linear trend analysis, so the increase in ET_0 may indicate increasing intensity in the hydrological cycle (Huntington 2006), which can be linked to recent climate change (Goyal 2004; Gong et al. 2006; Irmak et al. 2012; Huo et al. 2013). In addition to anthropogenic forcings, natural processes—mainly air circulation—are also widely linked to climate change (Kyselý and Domonkos 2006; Werner et al. 2000). An increasing persistence of the various types of circulation, including anticyclonic patterns, has recently been reported (Werner et al. 2000; Kyselý and Domonkos 2006). Along with the increasing frequency of blocking anticyclonic systems over Europe in recent decades, the number of low-pressure systems south of 55°N has decreased (Leckebusch and Ulbrich 2004). Therefore, the increasing evapotranspiration observed in Poland may be partly linked to the upward trend in the frequency and persistence of anticyclonic circulations. In this case, extreme ET_0 events have the potential to occur more frequently in the future.

5 Conclusions

The extremely high daily evapotranspiration values (90th percentile) observed in summer (June–August) in Poland during 1971–2010 ranged from 3.7 mm in northern and southern Poland to 4.6 mm in central Poland. The synoptic conditions on days with extreme evapotranspiration were compared with the average synoptic patterns during summer. This study demonstrated that the most favorable conditions for high ET_0 in Poland (central Europe) were elevated SLP (5 hPa anomalies northeast of Poland), elevated $z500$ (100 m anomalies over the southern Baltic Sea) and elevated $t850$ (>5 °C anomalies over Germany and western Poland). These synoptic patterns are typical of anticyclonic circulations and are accompanied by strong meteorological factors that directly control ET_0, including T_{max}, T_{min} and n as well as low values of RH. The increases detected in the aforementioned factors (apart from RH, which decreased) coincided with increases in ET_0, and these changes may result from the increase in the frequency of anticyclonic circulations in central Europe. However, the evapotranspiration tendency in this region requires more detailed analysis.

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