Temperature Forecast Accuracies of Polish Proverbs

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ABSTRACT

Proverbs are a part of traditional knowledge that has been increasingly acknowledged to be a valuable source of information for environmental policies. Proverbs on weather convey the cumulated experience of generations that provide guidelines for agricultural practices, everyday decisions, and other situations. Besides the value the proverbs have in their cultural setting, they also serve as an indicator of objective meteorological patterns. This study presents a comprehensive evaluation of the Polish temperature-related proverbs. From the collected corpus of more than 2000 Polish proverbs, 28 were related to temperature and provided concrete predictions and so were selected for further analysis. The proverbs were tested on the basis of temperature (minimum, maximum, and mean) data from 20 weather stations, located in Poland and the neighboring countries, for the period of 1951–2012. Harbingers and forecasts were identified and coded as 0 or 1. Proverb accuracies were then compared using Heidke skill scores and proportions of fulfilled proverbs. The proverbs' spatial and temporal contingencies were tested via generalized linear mixed models. Some proverbs provided a high proportion (up to 79%) of fulfilled proverbs. Furthermore, the accuracy of the proverbs was reversely proportional to chronological date (decreased with time), with values increasing toward the east and north directions of station locations. The observed changes in proverb accuracies may be attributed to the shift of Polish borders following the Second World War and the respective migration of the population.

1. Introduction

Recently, an increasing amount of attention has been focused by researchers and policy makers on environment-related traditional knowledge (TK) (Nakashima et al. 2012; Thaman et al. 2013; Hernández-Morcillo et al. 2014; Molnar and Berkes 2018). It is considered to be "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes et al. 2000, p. 1252).

Traditional knowledge represents a specific form of knowledge. From an anthropological perspective, Geertz (1983, p. 75) defines local knowledge as knowledge that is "practical, collective and strongly rooted in a particular place" that forms an "organized body of thought based on the immediacy of experience." Such concepts share the commonsense aspect and resemble Polanyi's claim related to the personal (Polanyi 1964) and tacit (Polanyi 1966; Tsoukas 2003) character of knowledge, which is embedded in personal experience and difficult to transfer in the formal, objective, and codified form that is required for scientific communication. Although TK is predominantly utilized in traditional tribal communities (indigenous knowledge), it also exists in modern rural (farmers' knowledge) and urban societies (Nakashima and Roue 2002). TK often refers to practices in agriculture, concerning crop cultivation (Leclerc et al. 2013; Barthel et al. 2013), the pastoral practice of transhumance (Oteros-Rozas et al. 2013), use of pesticides (Irwin 1995), fishing (Vogt et al. 2016), soil type assessments (Wynne 1996),

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forest management (Parrotta et al. 2016), and non-timber forest-product-related practices (Davidson-Hunt et al. 2013).

These factors have brought about a growing interest in TK in several respects. First, it may contribute to knowledge in cases in which scientific information is not sufficient. For example, for certain tropical plant species, or temperate mycorrhizal mushrooms, long-term scientific research has not been able to provide sufficient insights on successful cultivation (Donovan and Puri 2004). Second, there has been a recent increase in interest in the integration of TK into scientific frameworks and related policy-making decisions. This was observed in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change and many related publications (Parry et al. 2007; Berkes et al. 2000), as well as the Intergovernmental Platform for Biodiversity and Ecosystem Services (Thaman et al. 2013). Traditional knowledge can provide guidance for better-informed decision-making, overcoming weaknesses related to scientific knowledge (Irwin 1995; Molnar and Berkes 2018). In particular, participative processes involving TK are applied in policies related to fields including nature conservation (Ruiz-Mallén and Corbera 2013), climate change adaptation (Laidler 2006; Nyong et al. 2007; Vogt et al. 2016), risk management (Dekens 2007; Barua and Rahman 2018), and flood risk management (Kamarulzaman et al. 2016). Third, the practical applications of TK can be extended due to its role in wider cultural conglomerates (Ingold 2010). More specifically, TK is a valuable part of cultural heritage. Davidson-Hunt and Berkes (2003) point out that TK refers to the relationship between historical memory and the perception of the natural environment. In general, local knowledge can improve the process of environmental decision-making (Corburn 2003). As a result, the fusion of traditional and scientific knowledge should be treated as complementary (Moller et al. 2004). This approach has appeared in several studies related to environmental management, for example, research on population monitoring (Moller et al. 2004; Berkes 1999; Berkes and Kislalioglu Berkes 2009).

Nevertheless, the integration of science with TK is a demanding task (Nakashima and Roue 2002; Uprety et al. 2012) as our knowledge on TK is limited. Studies either treat TK as the central object of the analysis or aim at testing its accuracy (Leclerc et al. 2013). Studies focus in particular on changes in TK. They demonstrate that resilience (Gómez-Baggethun et al. 2013; Boillat and Berkes 2013), as well as TK erosion and hybridization, occurs when TK changes its nature and merges with other knowledge types, or the loss of TK when it disappears entirely (Gómez-Baggethun et al. 2013; Oteros-Rozas et al. 2013). Several studies have explored the consequences of changes in TK, and have demonstrated, for example, that such changes can induce higher flood losses (Jennings 2009). Another stream of research focuses on sources of TK (Davidson-Hunt et al. 2013) and its generational transmission (Oteros-Rozas et al. 2013; Barthel et al. 2013). Several studies have explored the significance of TK as a source of information on weather and climatic phenomena, including climate change. These studies have focused on, for example, knowledge on seasonal climate forecasting techniques by farmers in Tlaxcala, Mexico (Eakin 1999), knowledge on the weather and climate by indigenous Australians (Green et al. 2010) and the Maori in New Zealand (King et al. 2008), farmers' perception of climate change concerning agricultural adaptation strategies in rural Sahel (Mertz et al. 2009), and freshwater management in South Australia (Rayner 2019). The accuracy of weather and climate-related local knowledge was tested for Arctic communities (Gearheard et al. 2010; Huntington et al. 2004; Laidler 2006), Kenyan farmers (Leclerc et al. 2013), and traditional communities from Indonesian villages (Boissière et al. 2013). The studies generally revealed a high degree of TK accuracy.

In this study, we examine how much the TK represented in proverbs on climatic and weather phenomena actually reflects meteorological patterns. Proverbs serve many purposes relating to language, thought, and human activity. Besides their rhetoric, there is persuasive power and applicative knowledge. In addition, they usually recommend, explicitly or implicitly, a course of action (Arewa and Dundes 1964) and are often applied in complex and ambiguous situations. Furthermore, proverbs help to interpret natural phenomena (Lieber 1994). They are cultural phenomena that refer to cultural values and norms and serve as cultural and conversational resources to be deployed in appropriate situations while the validity and logical coherence of proverbs are not commonly verified (Anton 2009). They are used contextually by individuals that need to judge their usefulness in a particular circumstance. They serve as stored knowledge, which we examine here. In addition to the value the proverbs have in their cultural setting, in this study we look at proverbs as an indicator of objective meteorological patterns.

Weather proverbs often provide weather forecasts mainly related to agricultural practices. Such proverbs, similar to other forms of TK, are based on extensive observations from several generations, transmitted orally, are holistic, and are site-specific (Leclerc et al. 2013; Green and Raygorodetsky 2010; Ellen and Harris 2000;

Huntington et al. 2004; Berkes and Kislalioglu-Berkes 2009; Berkes 2009; Roncoli et al. 2009). In the past, agriculture-related weather proverbs provided a source of pop-up information for farming practices, as well as for everyday life decisions. They were substitutes for today's mid- and long-term climate prognoses, guiding the initiation or the end of fieldwork and harvesting. A few studies explored weather forecasts. Sadewasser (1976) discussed 30 weather-related beliefs in Kentucky. The analyzed beliefs comprised proverbs and other forms of traditional knowledge, such as proverbial comparisons and witticisms. A total of 20 beliefs that could be scientifically explained were generally related to rain. The 10 that were found not to be scientifically validated still had some elements of truth. The author attributed the inaccuracies in beliefs to their geographical transfer. For example, some beliefs were brought by migrants from Europe, and although they were functional in their original climate, this was not the case for Kentucky. Duncan (1991) compared the accuracy of weather-related proverbs in the continental and Scottish-speaking eastern region of Scotland with the Gaelic-speaking maritime west. Short-term predictions were found to be fairly accurate in Scotland, whereas longer-term predictions were fallible. For the Caledonian region, proverbs were less accurate. Furthermore, Kanno et al. (2013) tested the accuracy of weather proverbs in Zambia, revealing that proverbs are good climate indicators but not for all conditions.

Several studies have focused on weather-related proverbs in Poland. Biniak-Pieróg and Żyromski (2011) tested the forecasting accuracy of five proverbs, three of them concerning temperature and two concerning precipitation, for the city of Wrocław (southern Poland). The analysis demonstrated a higher accuracy for precipitation as the target event in the proverbs. The emphasis of the study was the testing of the dependence of accuracy on definitions of climatic conditions. For temperature-based proverbs, those with a subjective-based verification demonstrated a more substantial accuracy. Stopa-Boryczka et al. (2011) described the occurrence of regular heat and cold waves in Warsaw with the proverb "Barbara on water Christmas on ice," and determined the accuracy of the proverb as 53%. Furthermore, studies of Kołodziej et al. (2004), Liniewicz (1992), and Morawska-Horawska (1988) tested one or a few proverbs for a city or a larger territory. These studies generally indicate the limited forecasting accuracy of the proverbs.

In general, it is argued that the knowledge contained in proverbs is relevant for institutions dealing with ecosystem sustainability (Kurien 1998). The seasonality of weather phenomena was well represented in proverbs in the past. Despite this, current folk phrases do not determine actions in farming and other areas of life to such an extent as in the past. This is mainly due to the development of professional weather forecasts. However, they remain popular in mass media and in common speech.

In the current study, we examine how much the TK represented in temperature-related proverbs on climatic and weather phenomena reflects meteorological patterns. We define a proverb as a short, simple, generally well-known, and often metaphorical sentence that expresses a truth, wisdom, and morals based on commonsense or experience that is handed down from generation to generation (Honeck 1997; Mieder 2012). In many, if not all, languages, some proverbs (and sayings) concern weather predictions. We analyze the chronological and geographical contingency of the proverbs' accuracies. Possible causal relations of the observed patterns are investigated, and we refer to the issue of climate change.

2. Data and methods

a. *Study area and meteorological data*

We use Polish proverbs and meteorological data from Poland and its neighboring countries. Poland is located in central Europe, where a transition from oceanic to continental temperate climatic zones determines the weather. Oceanic features are frequent along western and coastal regions, while in the eastern area, the climate is predominantly continental. The central part of Europe is situated in such a way that several very diverse air masses affect it. According to the Köppen–Geiger classification, Poland (excluding its high mountainous regions) is located in the Dfb (warm summer humid continental) zone. During winter, especially from December to January, southwesterly and westerly air flows dominate east-central Europe that are linked to North Atlantic Oscillation. During summer, days with nondirectional anticyclonic type and days with northerly airflow were prevalent. Easterly circulation and also a high number of days with nondirectional cyclonic type are observed in April and May, and a low number of days with southerly airflow are observed in summer. Atmospheric circulation over this part of Europe is characterized by relatively high annual variability (Bartoszek 2017), resulting in significant interannual variations in temperature and precipitation. The annual average air temperature (1981–2010) ranges from 6°C in the northeast to 9.5°C in the southwest. Similar spatial distributions apply to mean extreme temperatures (based on 1981–2010): the highest values occurred in

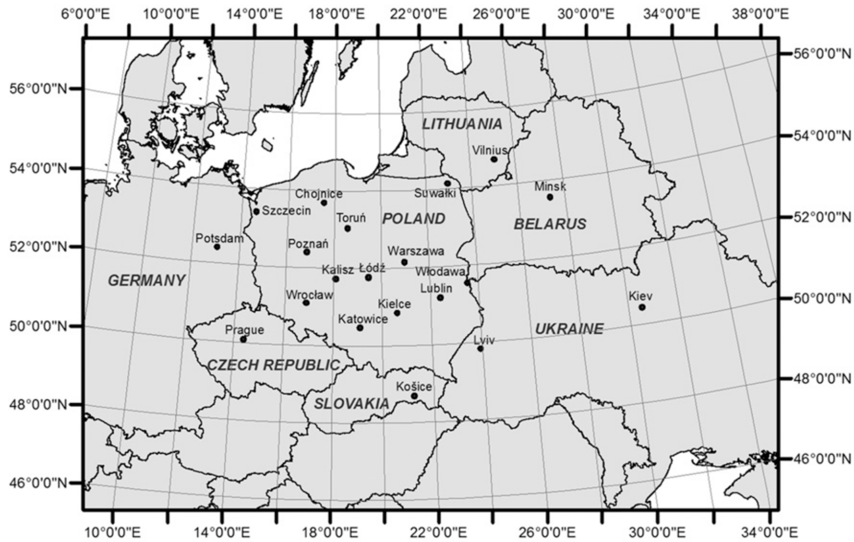

FIG. 1. Locations of meteorological stations included in the analysis.

southwestern Poland, and the lowest occurred in the northeast. More specifically, the 95th percentile of the maximum temperature and the 5th percentile of the minimum temperature ranges from 23° to above 28°C for warm periods and from −13° to −6°C for cold periods, respectively. The Polish climate, as with all countries across the globe, is changing. The mean annual air temperature anomaly trend for 1951–2018 (with 1981–2010 as a reference) is 0.26°C per 10 years {Climate Monitoring Bulletin of Poland, Institute of Meteorology and Water Management–State Research Institute [Instytut Meteorologii i Gospodarki Wodnej–Państwowy Instytut Badawczy (IMGW-PIB 2017)]}. Poland has four distinct seasons, which are typical for Europe: spring, a hot summer, autumn, and winter with snow coverage. Under this climate, the main crops are harvested once per year.

Meteorological data from 20 meteorological stations located in Poland and neighboring countries (Fig. 1) were included in the analysis. Data from Polish stations were obtained from IMGW-PIB. Data for the stations located outside Poland were acquired from the Royal Netherlands Meteorological Institute European Climate Assessment and Dataset project (KNMI ECA; Klein Tank et al. 2002).

Meteorological data were available over 62 years (1951–2012), except for Katowice and Kielce, Poland (1955–2012), and Prague, Czech Republic (1951–2004). Daily maximum, minimum, and average temperatures were applied for proverb parameterization.

b. Selection of proverbs

Most proverbs emerged in times when instrumental weather measurements did not exist, and thus translating them to measurable values proved to be a difficult task. For this reason, we decided to focus on proverbs referring to temperature since this is a precise measurable climatic feature, allowing for comparisons. Hence, a careful selection of proverbs was required for this study.

The selection procedure consisted of the following steps. First, two collections of proverbs compiled by Dygacz (2000) and Świrko (1990) were reviewed. Both collections contain a large number of proverbs that concern the weather. A total of 1940 weather- and climate-related proverbs were retrieved from the collections and constituted the main corpus. Most proverbs were related to agricultural practices.

Next, the selection criteria were developed. More specifically, to test proverb accuracy against meteorological data, the former needed to be in a specific format, allowing for comparisons with the latter. In particular, the proverbs had to offer a prediction and not only announce a fact.

From a meteorological point of view, the proverbs of the corpus can be divided into three groups. The first group refers to a correlation or relation between weather conditions on a certain day or in a certain month (a harbinger) and weather conditions on another day or month (a forecast). For example, "*Upały lipcowe wróżą mrozy styczniowe*" ("Hot July leads to frosts in January").

The second group is based on singularities, that is, events that often appear (Lamb 2011; Krępa and Ciaranek 2014; Małarzewski 2007; Kalnicky 1987). They indicate deviations from the typical course of atmospheric conditions in a given period, which often occur in specific periods. Proverbs of this group do not convey certain predictions, but warnings that, in a certain period, deviations from the expected temperature course may occur (e.g., high or low temperatures). For example, ''*Pankracy, Serwacy, Bonifacy, każdy swoim zimnem raczy*'' (''Pancras, Servatus and Boniface are great eccentrics, and they regale with cool'').

The third group is related to observations of regular repetitions of atmospheric events. These proverbs refer to certain border days, after which conditions usually change. They are consistent and generally result from a typical annual temperature course. This group of proverbs does not contain the typical harbinger and forecast, only information on conditions of certain events, such as the first or last frost of the year. For example, ''*Od świętej Anki chłodne wieczory i ranki*'' (''From the Saint Anne Day evenings and mornings will be cooler'').

Proverbs from the first class were used in our analysis. Their form, which comprises a harbinger (if) and forecast (then), allows us to analyze the accuracy via meteorological methods. Proverbs from the second and the third classes were excluded from the analysis because their predictions were straightforward. Moreover, analyzing them would require additional methods that would lead to difficulties in interpretation.

In the following step, the first group of proverbs was further refined, because many proverbs from this group could not be compared with meteorological data. This procedure was for the following reasons. Some proverbs 1) were very general [''*Czego lipiec i sierpień nie dowarzy tego wrzesień nie usmaży*'' (''What July and August do not boil, September cannot fry'')], 2) refer to complex circumstances, that is, several meteorological phenomena are involved at the same time, 3) refer to phenology [''*Na świętego Wita (15.06) zboże zakwita*'' (''For Saint Wit crops will flourish'')], 4) refer to phenomena that are difficult (or impossible) to measure [''*Święty Jakub jasny, zima sucha*'' (''If Saint Jakob is bright, winter will be dry'')], 5) are irrelevant in terms of prediction [''*Na świętego Hieronima jest deszcz albo go nie ma*'' (''Saint Hieronymus's Day is either rainy or dry'')], 6) use imprecise/metaphor language [''*Święty Wawrzyniec daje śliwkom rumieniec*'' (''Saint Lawrence paints the plums'')], 7) refer to typical phenomena (not a deviation from typical), 8) refer to movable holidays such as Easter [''*Jaka w ostatki pogoda taka się Wielkanoc poda*'' (''The weather in Shrove Tuesday shows the weather in Easter'')], or 9) contain subjective elements in weather descriptions, for example, a certain threshold can be perceived and recognized as a sign of spring in January, such as ''*Bój się w styczniu wiosny, bo marzec zazdrosny''* (''Be afraid of spring in January as March can be jealous''). Those that did not contain precise harbingers and/or forecasts were excluded from the analysis. Following the elimination process, 28 proverbs (Table 1) remained for which clear harbingers and forecasts about the temperature could be determined.

c. Harbinger parameterization and forecasts

The selected proverbs were parameterized such that concrete temperature values were assigned to expressions. The parameterization was evident for cases where a harbinger and a prediction referred to a specific temperature as a particular meteorological event (e.g., frost on a certain day). However, when the proverb referred to a relative term (e.g., cold weather during the month), a more complex parameterization was necessary. For such cases, two further methods were applied: quartile- and standard-deviation-based parameterization. In both, we compared the occurrence of the phenomenon in the given year with the average number of occurrences from the entire available period on the given day or month. For the quartile method, the occurrence of the event, for example, a ''hot month,'' is recognized when the parameter of a given event exceeded 75% of the average distribution of a given parameter (fourth quartile). Accordingly, a ''cold month'' was defined as the average monthly temperature below 25% of the average distribution of a given parameter (first quartile). In the standard deviation method, a temperature was referred to as the standard deviation of the occurrence of the given event from the mean of a referred period or a day. A ''hot month'' in this method occurs when it is warmer than the average by 1 standard deviation value. A ''cold month'' is colder than the average of 1 standard deviation value.

The main difference between these methods is that for the quartile method a cold or warm month occurs at a frequency of approximately once every four years. For the standard-deviation-based method, the frequency of occurrence is generally lower. Threshold values for both methods were based on those in Czerniecki and Miętus (2011). Eventually, we applied the standard deviation method in our analyses.

Following the parameterization, we verified the proverb weather forecasts, compared proverb accuracies, and tested how spatial and temporal changes influence the accuracy values.

d. Statistical analysis methods

Statistical analysis was conducted on the values obtained by the direct and the standard deviation parameterization methods. Figure 2 presents the methods and metrics applied to the analysis. The 28 proverbs were

TABLE 1. List of analyzed proverbs in Polish and with English translation, including key values taken for analysis (ID indicates the identification number for each proverb).

Proverb in Polish and in English	ID	Key parameter values and validation
Na Wszystkich Świętych (1.11.) jeśli ziemia skrzepła, cała zima będzie ciepła [If the ground is frozen on All Saints Day (1 Nov), all winter will be warm]	1	Max air temperature on 1 Nov < 0°C; mean air temperature from Dec until Feb > 75th percentile
Marek (25.04.) skwarem grozi, Bonifacy mrozi (14.05.) [If the Marek day (25 Apr) is threatening with the swelter the Boniface (14 May) freezes]	2	Max air temperature on 25 Apr > 25th percentile; min air temperature on 14 May < 0°C
Październik ciepły, będzie luty skrzepły (October warm, February will be frosted)	3	Mean air temperature in Oct > 75th percentile; mean air temperature in Feb of the following year < 25th percentile
Gdy 10 lutego mróz panuje, jeszcze 40 dni takich zwiastuje (When the frost reigns on 10 Feb, it heralds 40 such days)	4	Mean air temperature on 10 Feb < 0°C; mean air temperature until 22 Mar (leap year: 21 Mar) < 0°C
Pankracy (12.05.) i Serwacy (13.05.), gdy z przymrozkiem stają, zimne lata dają [If Pancras (12 May) and Servatus (13 May) come with ground frost, summers are cool]	5	Min air temperature on 12 and 13 May < 0°C; mean air temperature from Jun until Aug < 25th percentile
Styczeń, gdy z zimnem nie chodzi, marzec i kwiecień wychłodzi (If January does not come with cold, March and April will cool down)	6	Mean air temperature in Jan > 75th percentile; mean air temperature in Mar and Apr < 25th percentile
Jak na Marka (25.04.) człek nie chucha w Ogrodników (12–14.05.) trza kożucha [If at the Marek day (25 Apr), you do not have to warm your hands, then Pancras, Servatus, and Boniface (12–14 May) a sheepskin coat is needed]	7	Min air temperature on 25 Apr > 0°C; min air temperature for 12–14 May < 0°C
Jeżeli październik srogi to styczeń łagodny (If October is severe, January is mild)	8	Mean air temperature in Oct < 25th percentile; mean air temperature in Jan > 75th percentile
Gdy luty zimny i suchy, sierpień będzie gorący (When February is cold and dry, August will be hot)	9	Mean air temperature in Feb < 25th percentile; mean air temperature in Aug > 75th percentile
Ciepły marzec, zimny kwiecień (Warm March, cold April)	10	Mean air temperature in Mar > 75th percentile; mean air temperature in Apr < 25th percentile
Mrozy w Trzech Króli (6.01.) potrwają do Gietruli (17.03.) [Frosts on the Three Kings Day (6 Jan) remain until the Gietrula day (17 Mar)]	11	Max air temperature on 6 Jan < 0°C; last days with max air temperature < 0°C on 17 Mar
Upały lipcowe wróżą mrozy styczniowe (Heats in July forecasts frosts in January)	12	Mean max air temperature in Jul > 75th percentile; mean min air temperature in Jan (next year) < 25th percentile
Barbara po lodzie (4.12.) Boże Narodzenie (25.12.) po wodzie [Barbara (4 Dec) on ice, Christmas (25 Dec) on water]	13	Max air temperature on 12 Dec < 0°C; min air temperature on 25 Dec > 0°C
Gdy ciepło na Dominika (4.08.), ostra zima nas dotyka [When the heat is on the Dominik day (4 Aug), a sharp winter touches us]	14	Mean air temperature on 4 Aug > 75th percentile; mean air temperature from Dec until Feb < 25th percentile
Gdy październik ciepło trzyma, zwykle mroźna będzie zima (When October is warm, it is usually a cold winter)	15	Mean air temperature in Oct > 75th percentile; mean air temperature from Dec until Feb < 25th percentile
Św. Katarzyna (25.11.) po lodzie, Boże Narodzenie (25.12.) po wodzie [Saint Catherine (25 Nov) on ice, Christmas (25 Dec) on water]	16	Max air temperature on 25 Nov < 0°C; min air temperature on 25 Dec > 0°C
Gdy w pierwszym tygodniu sierpnia spieka, zima ciężka, śnieżna, długa czeka (When in the first week of August it is hot, a heavy and snowy winter is coming)	17	First week of Aug mean max air temperature > 25th percentile; mean air temperature from Dec until Feb < 25th percentile
Styczeń mrozi, lipiec skwarem grozi (If January freezes, July threatens with heat)	18	Mean air temperature in January < 25th percentile; mean air temperature in July > 75th percentile
Od Cypriana (10.02.) aż do Jana Kapistrana (28.03.), gdy pogoda jest zasrana, to od Jana (28.03.) do Jerzego (19.04.) ciągle jeszcze nic nowego [If from the Cyprian day (10 Feb) to the John Kapistran day (28 Mar) the weather is cheesy, from John (28 Mar) to Jerzy (19 Apr) nothing new happens]	19	Mean air temperature from 10 Feb < 5°C; mean air temperature from 28 Mar to 19 Apr < 5°C
Gdy po gorącym lipcu sierpień chłodzi, twarda zima i duży śnieg zaszkodzi (When, after a hot July, August cools, hard winter and big snow will hurt)	20	Mean air temperature in Jul > 75th percentile and in Aug < 25th percentile; mean air temperature from Dec until Feb < 25th percentile

TABLE 1. (*Continued*)

Proverb in Polish and in English	ID	Key parameter values and validation
Kiedy Gromniczna (2.02.) zimę traci, to św. Maciej (24.02.) ją wzbogaci [When the Candlemas (2 Feb) loses winter, the Saint Matthew day (24 Feb) will strengthen it]	21	Mean air temperature on 2 Feb > climate normal; mean air temperature on 24 Feb < climate normal
Gdy ciepło w luty, zimno w marcu bywa, paszy trzeba zachować, by jej potem nie kupować (When warm in February, March is cold and in March you have to keep the feed, not to buy it later)	22	Mean air temperature in Feb > 75th percentile; mean air temperature in Mar < 25th percentile
Kiedy na Barbarę (4.12.) błoto, to na Boże Narodzenie (25.12.) sanna jak złoto [When the Barbara day (4 Dec) is muddy, Christmas (25 Dec) is on a toboggan]	23	Min air temperature on 4 Dec > 0°C; max air temperature on 25 Dec < 0°C
Kiedy lipiec chłodzi, twarda zima i śnieg nadchodzi (When July cools, hard winter and snow are coming)	24	Mean air temperature in Jul < 25th percentile; mean air temperature from Dec until Feb < 25th percentile
Św. Katarzyna (25.11.) po wodzie, Boże Narodzenie (25.12.) po lodzie [Saint Catherine (25 Nov) on water, Christmas (25 Dec) on ice]	25	Min air temperature on 25 Nov > 0°C; max air temperature on 25 Dec < 0°C
Jak ciepło na Macieja (24.02.) to już wiosny nadzieja [If the Matthew day (24 Feb) is warm there is a hope for spring]	26	Mean air temperature on 24 Feb > 5 C; mean air temperature until 21 Mar > 0°C
Gdy Zbigniew i Patryk (17.03) mrożą ludziom uszy, zima jeszcze 2 niedziele mrozem i śniegiem prószy [When Zbigniew and Patrick (17 Mar) are freezing people's ears, two more Sundays of winter freezing and snows]	27	Min air temperature on 17 Mar < 0°C; mean air temperature for the following two weeks < 2°C
Gdy Maciej święty (24.02.) cokolwiek lodu nie stopi, będą długo chuchali w zimne ręce chłopi [If Saint Matthew (24 Feb), does not melt ice, peasants will long puff to warm their cold hands]	28	Max air temperature on 24 Feb < 0°C; mean air temperature for the following two weeks < 0°C

tested against available temperature records for 20 meteorological stations ($n = 33\,345$). First, we prepared 2×2 contingency tables. In the meteorological forecasting, predicted weather events were compared with observed weather events. In the case of the analyzed proverbs, "prediction" was assumed as conditional because of its dependence on harbinger occurrence. In the following, we describe the logic of converting a proverb into the format of a contingency table using the example of "Saint Catherine on ice, Christmas on water." The harbinger ("Saint Catherine on ice") was treated as a condition of the forecast (which refers to future phenomena), whereas the prediction of the proverb ("Christmas on water") was treated as the observed event (Table 2).

Following this, we verified the forecasts provided by the proverbs via their skill scores (Heidke skill score), detection probabilities, false alarm ratios (FAR), and baseline occurrences [applied metrics are summarized in Table 3; the terminology is based on Hogan and Mason (2012)]. The Heidke skill score is considered to be the most informative of the applied metrics because it assesses the quality of proverb forecasts relative to random occurrences of the event (in this case, the baseline

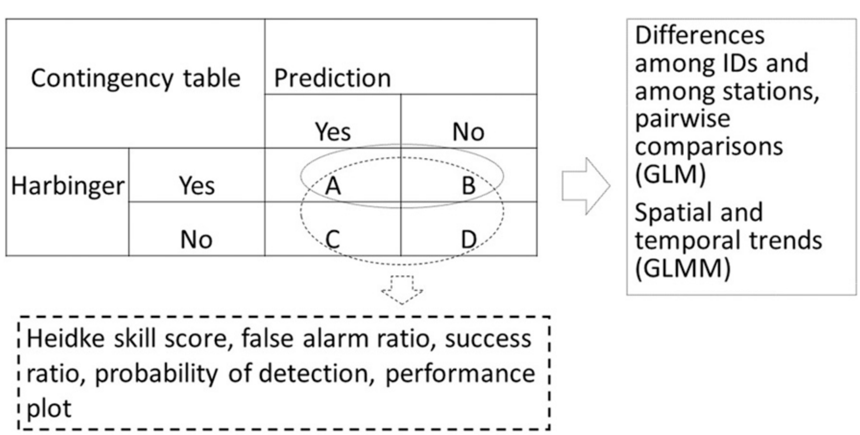

FIG. 2. Scheme of the applied methods, metrics, and data sources.

TABLE 2. A 2 × 2 contingency table for proverbs. In italics, an example is given of the proverb "Saint Catherine on ice, Christmas on water." The sum of the numbers in A, B, C, and D gives the number of cases for the proverbs (1234 cases: 19 stations with data for 62 years, and one station with data for 56 years).

		Event observed (prediction, e.g., "*Christmas on water*")	
		Yes	No
Event forecast (harbinger, e.g., "*Saint Catherine on ice*")	Yes	A (51)	B (178)
	No	C (227)	D (778)

frequency of the event). Performance plots were used to illustrate the verifications of the metrics (Roebber 2009). On the performance plot the probability of detection (POD; the proportion of detecting a true event), success ratio (SR; 1 − proportion of mistakes in the case of a positive forecast), bias (the ratio of positive and negative forecasts), and critical success index (CSI; the number of truly forecast events divided by the sum of truly forecast + falsely forecast + not detected events) are presented. With the help of these metrics, we can compare the proverbs' weather forecast abilities.

The contingence-table-based verification approach, however, goes beyond the actual statements formulated in the proverbs, because it includes all events in which the harbinger is false (in strict terms, proverbs do not deal with such cases). Therefore, we tested proverbs' accuracy sensu stricto, that is, only those cases in which the harbinger statement was fulfilled ("A" and "B") were recorded in the contingency table (see Table 3 for reference). This procedure gave us $n = 10\,165$ cases. Proverb accuracy from this database is expressed as the "fulfilled proverbs proportion" (FPP) and is equal to $A/(A + B)$ records of the contingency table.

We tested the variation of the FPP among proverbs and across space and time. We compared FPP via the generalized linear model (GLM) with the logit function (Zuur et al. 2009). The GLM equation is described as follows:

$$\mathrm{logit}(p_i) = \alpha + \beta \times \mathrm{ID}_i + \varepsilon,$$

where p_i is the probability of the fulfilled proverb i, ε is the residual [$\varepsilon \sim N(0, \sigma^2)$], ID is the identification number of proverbs, and α and β are coefficients of the equations.

The post hoc Tukey test with the Holm correction (Hothorn et al. 2008) was applied to avoid problems of multiple comparisons for pairwise comparison. Similarly, a model for fulfilled proverbs at each of the meteorological stations allowed for pairwise comparisons with Holm corrections among stations (Fig. 3).

Following this, we simultaneously tested temporal and spatial dependencies to investigate the influence of meteorological observation time and location on proverb accuracies (expressed as "probability of fulfilled proverbs"). We used generalized linear mixed models (GLMM; Bolker et al. 2009; Zuur et al. 2009) with the logit function and the proverb ID as the random variable. This method allows us to assess the influence of observation time and location on the accuracy of all of the proverbs. The probability of the fulfilled predictions was tested as a function of the observation year and the geo-coordinates of the meteorological stations. The GLMM equations are as follows:

$$\mathrm{logit}(p_{ij}) = \alpha + \beta_1 \times \mathrm{year}_{ij} + \beta_2 \times \mathrm{latitude}_{ij} + \beta_3 \times \mathrm{longitude}_{ij} + a_i,$$

The notation logit stands for the logistic link function (that ensures that confident bands are between 0 and 1), where p_{ij} is the probability that the ith proverb is fulfilled at the jth observation (characterized by a given year and site). The term a_i is the random intercept (in our case, the influence of proverb ID), where $a \sim N(0, \sigma^2)$.

TABLE 3. Description of metrics and definitions applied throughout this paper, following Hogan and Mason (2012) and Roebber (2009). "Fulfilled proverbs proportion" is a term used in this paper.

Name of measure	Definition	Range
Base rate s	$s = (A + C)/(A + B + C + D)$	[0, 1]
Probability of detection (hit rate)	$A/(A + C)$	[0, 1]
False alarm ratio = 1 − (success ratio)	$B/(A + B)$	[0, 1]
Bias	$(A + B)/(A + C)$	[0, infinite]
Heidke skill ratio	$(A + D - A_r - D_r)/(n - A_r - D_r)$, where $A_r = (A + B) \times (A + C)/n$ and $D_r = (B + D) \times (C + D)/n$	[−1, 1]
Critical success index	$A/(A + B + C)$	[0, 1]
Fulfilled proverbs proportion	$A/(A + B)$	[0, 1]

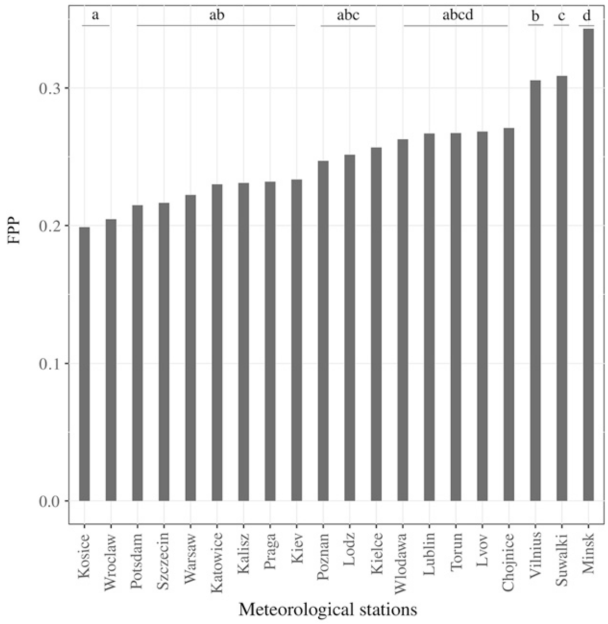

FIG. 3. FPP for the meteorological stations. Proportions are calculated for 28 proverbs from all years (n = 10 165 cases). Proportions sharing the same letter are not significantly different from each other ($P < 0.05$ level, GLM with logit link, and post hoc test with Holm correction).

Models were validated via the visual inspection of the residuals, assessing the potential lack of normality, heterogeneity, and the presence of influential observations (Zuur et al. 2009; Bolker et al. 2009). Visual inspections did not identify any of these violations, thus fulfilling the preconditions required for the application of the aforementioned models.

All calculations were performed in the R software product, version 3.5.1. (R Core Team 2018), using several R packages: nlme and lme4 for modeling, ggplot2 for plotting figures, multcomp for multiple comparisons of proverbs, and the verification package for 2 × 2 contingency-table-based calculations and performance plots (Pinheiro et al. 2015; Bates et al. 2015; Wickham 2009; Hothorn et al. 2008; NCAR Research Applications Laboratory 2015).

3. Results

a. Proverb forecast verification and accuracy

A relatively low proportion of the proverb forecasts were observed to entail successful predictions (Table 4). The POD and FAR for all proverbs were 0.25 and 0.59, respectively. The Heidke skill score calculated for all proverbs was slightly above 0 (0.01), indicating a very low prediction potential. The prediction performance of all proverbs is presented in Fig. 4. Higher POD scores and SRs (1 − FAR) imply better predictions. Thus, the upper-right area of the performance plot indicates higher accuracies. Figure 4 also presents the CSI and bias levels. A total of 16 proverbs were observed to have positive Heidke skill scores; however, only 8 exhibited a skill score above 0.1 (Table 4). The highest skill scores (0.47 and 0.43) belonged to proverbs number 27 ''*Gdy Zbigniew i Patryk (17.03) mrożą ludziom uszy, zima jeszcze 2 niedziele mrozem i śniegiem prószy*'' [''When Zbigniew and Patrick (17 March) are freezing people's ears, on two more Sundays winter freezing and snows''] and number 28 ''*Gdy Maciej święty (24.02) cokolwiek lodu nie stopi, będą długo chuchali w zimne ręce chłopi*'' [''If Saint Matthew (24 February), does not melt ice, peasants will long puff to warm their cold hands''], respectively. These two proverbs are the closest to the upper-right corner of Fig. 4. It indicates that a relatively high POD is paired with a relatively low FAR (high SR as SR = 1 − FAR). Both cases have a bias around 1.5, and proverb number 28 shows a higher CSI. Thus, these two proverbs are also ''the best'' in terms of forecasting metrics. Skill scores greater than 0.2 (0.28 and 0.23) were determined for proverbs number 24 ''*Kiedy lipiec chłodzi, twarda zima i śnieg nadchodzi*'' (''When July cools, hard winter and snow are coming'') and number 26 ''*Jak ciepło na Macieja (24.02.) to już wiosny nadzieja*'' [''If Matthew day (24 February) is warm there is a hope for spring''], respectively. These two proverbs show a lower SR (event stated in the harbinger is not fulfilled), bias level 1.5–2, and CSI index 0.2–0.3; see Fig. 4).

In general, the proverbs exhibited relatively low overall FPP (26.58% for all proverbs). A total of 17 proverbs exhibited a probability of less than 25% for successful predictions. The ''best'' proverb provided successful predictions with a probability of 83% (Fig. 5 and Table 4). Moreover, the three best proverbs were also those with the highest forecast verification (numbers 26–28). However, for proverb number 25 [''*Św. Katarzyna po wodzie, Boże Narodzenie po lodzie''* (''Saint Catherine on water, Christmas on ice'')] a significant difference between accuracies from the two metrics was observed, with 43% of fulfilled predictions yet a Heidke score of just 0.07. Similar differences occurred for proverb numbers 21–23, where fulfilled predictions were greater than 35% while Heidke scores were much lower (−0.15, 0.02, and 0.01, respectively). These proverbs exhibit a relatively lower POD with relatively higher SRs (see Fig. 4). These differences may indicate that these proverbs do not provide reliable information for the cases in which the harbinger is not fulfilled.

In general, the proverbs refer to relatively rare phenomena (baseline for all of the proverbs is 0.19). Furthermore, a total of seven proverbs refer to events

TABLE 4. Verification of weather forecasts provided by proverbs. The values are calculated from 2 × 2 contingency tables. The values having skill scores that are higher than zero are in boldface type, indicating that the forecast has some skill in predicting an event with a higher probability than a random occurrence of the event (baseline).

Proverb ID	POD [hit rate (SE)]	FAR (SE)	Heidke skill score (SE)	*s*	FPP (%)
1	0	0.99 (0)	−0.05	0.01	0
2	0	0.99	−0.01	0.03	0
3	0.16 (0.02)	0.82 (0.02)	−0.12 (0.03)	0.16	0
4	0.02 (0.01)	0.22 (0.01)	**0.01 (0)**	0.01	0.02
5	0.02 (0.01)	0	**0.04 (0.01)**	<0.01	0.02
6	0.03 (0.01)	0.94 (0.03)	−0.04 (0.03)	0.05	0.03
7	0.06 (0.01)	0.2 (0.04)	−0.01 (0.01)	0.06	0.56
8	0.06 (0.01)	0.1 (0.02)	−0.03 (0.03)	0.13	0.08
9	0.08 (0.02)	0.93 (0.02)	−0.07 (0.03)	0.15	0.08
10	0.08 (0.02)	0.92 (0.02)	−0.09 (0.03)	0.16	0.08
11	0.12 (0.01)	0.37 (0.05)	**0.06 (0.01)**	0.08	0.11
12	0.1 (0.03)	0.91 (0.02)	−0.02 (0.03)	0.04	0.14
13	0.18 (0.02)	0.81 (0.02)	−0.07 (0.03)	0.23	0.18
14	0.2 (0.02)	0.4 (0.03)	**0.08 (0.02)**	0.16	0.20
15	0.21 (0.03)	0.79 (0.03)	**0.06 (0.03)**	0.16	0.21
16	0.22 (0.03)	0.82 (0.02)	0 (0.02)	0.23	0.22
17	0.24 (0.02)	0.35 (0.03)	**0.14 (0.02)**	0.16	0.23
18	0.25 (0.03)	0.75 (0.03)	**0.11 (0.03)**	0.16	0.25
19	0.29 (0.01)	0.05 (0.01)	**0.12 (0.01)**	0.24	0.29
20	0.34 (0.04)	0.78 (0.02)	**0.11 (0.03)**	0.23	0.35
21	0.37 (0.02)	0.51 (0.02)	−0.15 (0.03)	0.44	0.37
22	0.39 (0.02)	0.63 (0.02)	**0.02 (0.01)**	0.38	0.39
23	0.4 (0.02)	0.24 (0.02)	**0.01 (0.01)**	0.39	0.39
24	0.47 (0.07)	0.69 (0.03)	**0.28 (0.03)**	0.17	0.43
25	0.43 (0.02)	0.5 (0.02)	**0.07 (0.02)**	0.39	0.43
26	0.52 (0.04)	0.73 (0.02)	**0.23 (0.03)**	0.06	0.51
27	0.66 (0.05)	0.56 (0.03)	**0.47 (0.04)**	0.13	0.66
28	0.83 (0.02)	0.45 (0.01)	**0.43 (0.02)**	0.51	0.83

that are extremely rare (<0.1), and among these, number 5 demonstrates a slightly positive skill.

Most of the proverbs with a high performance refer to a shorter time period (medium-term forecast). However, seasonal forecasts are also present [proverb number 24 ''*Kiedy lipiec chłodzi, twarda zima i śnieg nadchodzi*'' (''When July cools, hard winter and snow are coming'')].

b. Influence of observation year and location on FPP

The GLMM equation was applied with the logit function and proverb ID as the random variable:

$$\begin{aligned}\text{logit}(p_{ij}) &= \alpha + \beta_1 \times \text{year}_{ij} + \beta_2 \times \text{latitude}_{ij} + \beta_3 \times \text{longitude}_{ij} + a_i \\ &= -7.3 - 0.16 \times \text{year}_{ij} + 0.03 \times \text{latitude}_{ij} + 0.1 \times \text{longitude}_{ij} + a_i,\end{aligned}$$

where $a_i \sim N(0, \sigma^2)$ and $\sigma^2 = 2.782$.

The observation years had an influence on the FPP (Fig. 6). The proverbs provided accurate predictions at a greater frequency at the beginning of the observation period. With time, the proverb accuracy significantly decreased, exhibiting a linear trend significant at the $P < 0.001$ level.

The geographical coordinates of the 20 meteorological stations also significantly influenced the probabilities of fulfilling proverb predictions. The success of proverb predictions was more likely at meteorological stations located at more-eastern longitudes [$\beta = 0.1$, standard error (SE) = 0.01, and $P < 0.001$, where β is the coefficient of the fixed effect] and higher latitudes ($\beta = 0.03$, SE = 0.006, and $P < 0.001$) (Fig. 7).

The FPP by meteorological station is presented in Fig. 7. The proverbs with the highest accuracy were associated with Minsk, Belarus (35.73%). Post hoc comparisons with the Holm correction showed that the differences between stations were, in many cases, nonsignificant.

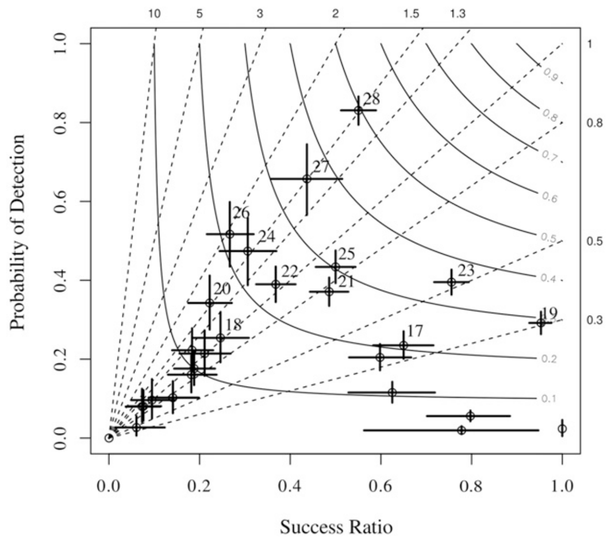

FIG. 4. Performance diagram visualizing proverb forecast verification, summarizing the success ratio (1 − FAR), probability of detection (equal to hit rate), bias, and critical success indices. Circles represent the mean values obtained for individual proverbs, dashed lines represent bias scores, with labels on the outward extension of the line, and labeled solid contours are CSIs. The 95% probability ranges of POD and SR (presented by vertical and horizontal lines forming a cross) were estimated from 10 000 bootstrap samples showing the same distribution characteristics. The proverb IDs are shown on the plot for the 10 proverbs showing the highest FPP. Performance diagrams are described in detail by Roebber (2009).

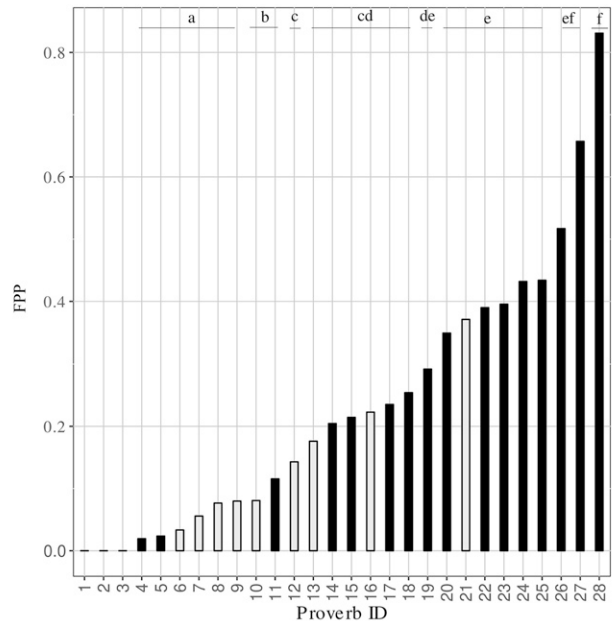

FIG. 5. FPP of the 28 proverbs. Proportions are calculated for 28 proverbs from all years and locations (n = 10 165 cases). Proportions sharing the same letter are not significantly different from each other ($P < 0.05$ level, GLM with logit link, and post hoc test with Holm correction). Proverbs with negative Heidke skill scores are indicated with lighter color bars.

4. Discussion

The analysis showed that the successful prediction rate of the proverbs was relatively low. Verification results revealed that 16 proverbs showed a certain amount of forecasting skills. However, only one-third of the proverbs exhibited skill scores over 0.1, and only two had skill scores over 0.4. In addition, the FPP was less than 25% for 17 proverbs, with three proverbs exhibiting an accuracy greater than 50%.

In comparing the proverbs with other sources of TK, it is seen that cultural memory on recent climatic events demonstrated a higher accuracy for Inuit, Indonesian, and African communities (Gearheard et al. 2010; Boissière et al. 2013; Leclerc et al. 2013). Proverbs reflect long-lasting cultural memory, and predictions often concern a long time and a relatively large area (with differences in climatic conditions). This characteristic complicates the determination of accuracy. Nevertheless, this study does not intend to assess whether determined proverb accuracies are low or high in absolute terms. Most, if not all, studied Polish proverbs provide long-term weather predictions (more than a month, up to 1.5 years). Thus, the low accuracies observed for the analyzed proverbs could be compared with the accuracy of weather forecasts that are based on long-term meteorological models, which also exhibit limited levels of accuracy for more than a month in advance. For example, the European Centre for Medium-Range Weather Forecasts model, which is one of the most frequently quoted seasonal forecast models, has been assessed as marginally applicable for central Europe in most cases (Weisheimer and Palmer 2014).

We also examined whether proverbs' accuracy depends on variations over time and space. Our analysis indicates that the FPP decreased over time (1951–2012). This result may be attributed to the impacts of climate change, for example, changes in atmospheric circulation patterns (Bárdossy and Caspary 1990) and climate extremes, particularly in central and eastern Europe (Tomczyk and Bednorz 2016; Graczyk and Kundzewicz 2014). An additional explanation refers to the change of the European landscape. Most proverbs are closely linked to past agricultural practices. However, European agricultural landscapes have evolved drastically due to interactions between social and ecological systems and industrial and social transformations during the past 150 years (Grove and Rackham 2001). These processes influence the local climate and may also weaken the predictive power of the proverbs.

Our results reveal that a closer bearing of the meteorological stations to the north and east indicates a

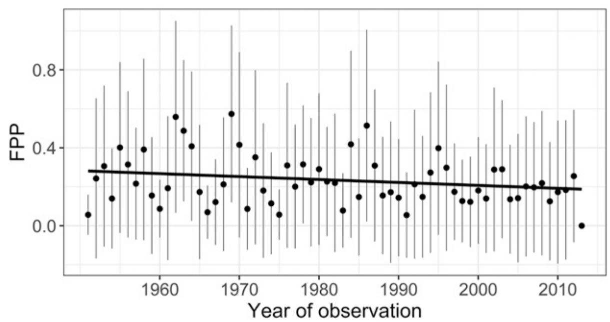

FIG. 6. Plot showing decreasing FPP with time, using a GLMM with logit function; $\beta = -0.16$, SE = 0.020, and $P < 0.001$. The database consisted of 10 165 cases and 28 proverbs. The full description of the model is given in the main text. Mean proportions (dots) and ranges of standard deviations (whiskers) are shown.

greater success in predictions. Of the meteorological stations, the proverbs with the highest accuracies were observed in Minsk, Vilnius (Lithuania), and Suwalki (Poland). We can follow the argument of Sadewasser (1976) that inaccuracies of proverbs can be attributed to the geographical transfer of populations that use them to explain this phenomenon. We have no information on the areas where the analyzed proverbs emerged. However, following the Second World War, Poland was displaced by some 200 km westward, with the population displaced accordingly. Thus, the proverbs may refer to the climate of areas that are more eastward when compared with the current borders of Poland, that is, the areas nowadays in Belarus, Lithuania, and Ukraine.

In conclusion, this comprehensive test of proverb accuracy demonstrated that only a few tested proverbs provide relatively reliable forecasts, although accuracy levels exhibit spatial heterogeneity and decrease with time. The causalities of the detected patterns call for further investigation.

This study has several limitations. First, only proverbs that refer to temperature and exhibit a conditional formulation were analyzed. Including other proverbs could perhaps demonstrate different accuracy levels and sensitivities to space and time. Second, temperature data were taken from 20 stations, because this was the available dataset at the time of analysis. Currently, data from more stations are available. Including more stations in the analysis could provide additional validation. Third, the reason for the differences in the proverbs' forecast accuracy was not investigated in this study. Including the analysis of the proverbs' content would

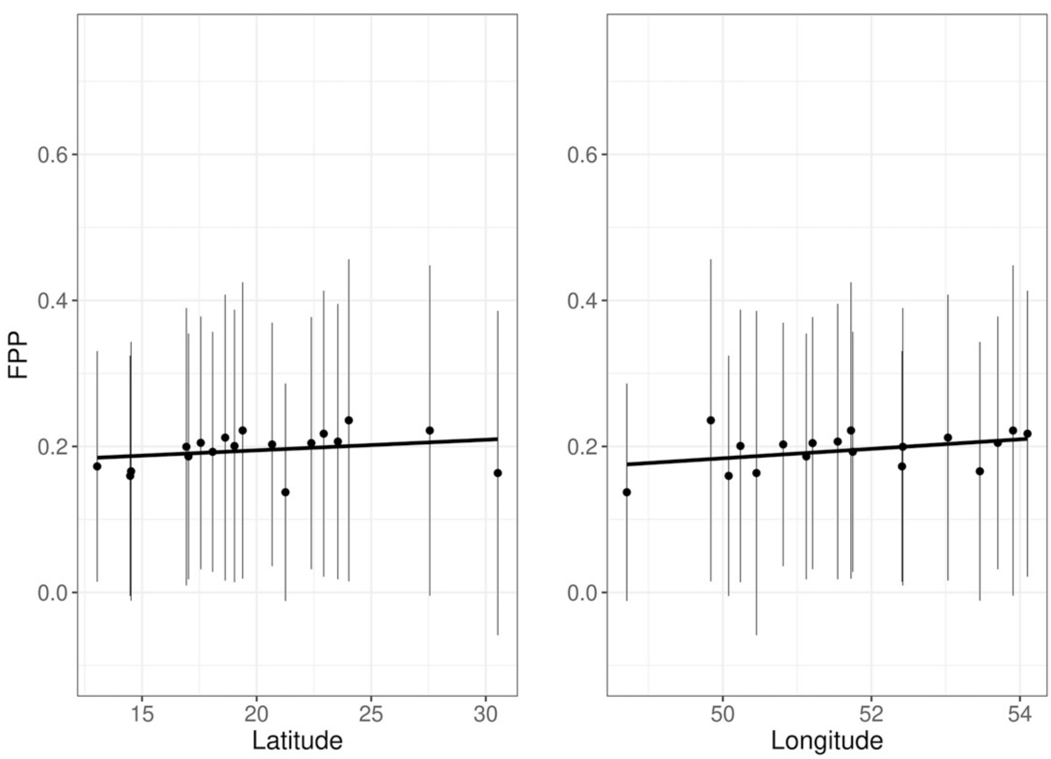

FIG. 7. Influences of meteorological stations' geographical location on FPP, using a GLMM with logit function; β and SE with longitude = 0.09 and 0.020, respectively; β and SE with latitude = 0.03 and 0.020, respectively; $P < 0.001$ in both cases. The database consisted of 10 165 cases and 28 proverbs. The full description of the model is given in the text. Mean proportions (dots) and ranges of standard deviations (whiskers) are shown.

perhaps give insights in this respect. In particular, inclusion of proverbs' lead time with reference to year-to-year variability could offer explanations for the accuracy differences. Also, controlling the event frequency offers an interesting path for further investigation. We calculated Heidke skill scores that include the baseline frequencies of the given event. A detailed analysis of the extremes or rare events with regard to accuracy would also be another possible option for further analyses.

5. Conclusions

Traditional knowledge has been increasingly acknowledged as an underutilized and valuable information source for environmental policies and as a complementary tool for scientific results. Weather-related proverbs, in addition to the value they have in their cultural setting, also serve as an indicator of objective meteorological patterns. In this study, we performed comprehensive research on Polish weather-related proverbs, examining the success rate of their predictions, and we analyzed the chronological and geographical contingency of the proverbs' predictions. A total of 28 proverbs referring to temperature were precisely parameterized. Meteorological observations from 20 stations from Poland and neighboring countries over 62 years (1951–2012) were used as the data source. The analysis demonstrated that only a few tested proverbs provide relatively reliable forecasts, although accuracy levels exhibit spatial heterogeneity and decrease with time. The causalities of the detected patterns call for further investigation.

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