Reg Environ Change (2017) 17:915–928
DOI 10.1007/s10113-016-1082-4

ORIGINAL ARTICLE

Changing weather and climate in Northern Ghana: comparison of local perceptions with meteorological and land cover data

Katherine L. Dickinson[1,2] · **Andrew J. Monaghan**[1] · **Isaac J. Rivera**[2] · **Leiqiu Hu**[1] · **Ernest Kanyomse**[3] · **Rex Alirigia**[3] · **James Adoctor**[3] · **Rachael E. Kaspar**[2] · **Abraham Rexford Oduro**[3] · **Christine Wiedinmyer**[1]

Received: 19 June 2015 / Accepted: 10 November 2016 / Published online: 26 December 2016

Abstract Local perspectives on changing weather and climate and analyses of meteorological data represent two different but potentially complementary ways of knowing about the local-scale impacts of global climate change. This paper uses quantitative social survey data from the Kassena and Nankana Districts of Northern Ghana and the best available meteorological records to examine recent changes in weather patterns for this region. The most commonly mentioned changes perceived by respondents include changes in the timing or predictability of rains, and overall drier conditions. Both of these changes are corroborated by precipitation datasets: The onset of the peak rainy season has shifted progressively later over the past decade, by up to a month, and the rainy season has been drier over the past 3–5 years compared to the past 10–35 years, mainly due to lower rainfall during peak months (June and July). Many respondents also said that conditions had become windier, and we find that this perception varies spatially within the districts, but no meteorological data are available for this climate parameter in this region. The common perception that deforestation is responsible for observed changes in weather patterns is partly supported by Landsat imagery indicating a reduction in dense vegetation in recent decades. This comparison highlights some of the potential benefits and challenges involved in giving more voice to community perspectives in the co-production of knowledge on global climate change and its regional impacts.

Keywords Climate change · Local knowledge · Local impacts · West Africa · Ghana

---

Editor: Virginia Burkett.

Electronic supplementary material The online version of this article (doi:10.1007/s10113-016-1082-4) contains supplementary material, which is available to authorized users.

✉ Katherine L. Dickinson
katied@ucar.edu

Andrew J. Monaghan
monaghan@ucar.edu

Isaac J. Rivera
isaac.rivera@ucdenver.edu

Leiqiu Hu
leiqiu@ucar.edu

Ernest Kanyomse
Ernest.Kanyomse@navrongo-hrc.org

Rex Alirigia
Rex.Alirigia@navrongo-hrc.org

James Adoctor
jkadoctor@yahoo.com

Rachael E. Kaspar
rachael.kaspar@colorado.edu

Abraham Rexford Oduro
Abraham.Oduro@navrongo-hrc.org

Christine Wiedinmyer
christin@ucar.edu

[1] National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA

[2] University of Colorado-Boulder, Boulder, CO 80309, USA

[3] Navrongo Health Research Centre, Navrongo, Ghana

Introduction

While climate change may be a global phenomenon, its effects are borne out locally in communities worldwide. A growing body of research has focused on predicting and analyzing the local impacts of climate change (Barros 2014). However, important gaps remain in our collective understanding of how to best merge different sources of knowledge of local climate change effects. Specifically, what is the role of local knowledge and perceptions in this process? How should data from meteorological records and climate models be integrated with local perspectives in order to more fully understand and respond to climate impacts? When local perceptions are at odds with measured trends, which data source is "right," given that both have some degree of uncertainty? How should each type of knowledge be used to inform mitigation and adaptation policies moving forward?

This paper addresses these important questions using a case study from Northern Ghana. Perceptions of changes in local weather patterns are systematically measured and compared with trends discerned from available observational and modeled climate datasets over the same geographic area. The combined components of this comparison—the quantitative social science methodology and the multivariate climate data analysis—appear to be unique in the small body of prior literature comparing public perceptions with climate data trends in a developing country setting. We assess the extent to which the changes being perceived by the study population can be detected in the climatic datasets. Our purpose in making this comparison is not to determine whether local perceptions are "accurate," but rather to lay out the results of two different "ways of knowing" about the climate system in this area (Goldman 2007; Brace and Geoghegan 2011; Berkes 2012). We then provide some discussion of the strengths and limitations of both types of information, along with challenges for making side-by-side comparisons between the two. We offer suggestions for ways in which both types of data could be collected and analyzed to facilitate similar comparisons moving forward, while also acknowledging key differences that will persist between these different types of information and the questions they are best suited to address.

Local knowledge of climate impacts

A growing body of the literature emphasizes the importance of incorporating local knowledge and perspectives into discussions of climate change and its impacts (Riedlinger and Berkes 2001; Hulme 2008; Orlove et al. 2010; Alexander et al. 2011; Klein et al. 2014). There are several ethical, scientific, and practical reasons for giving increased attention to local perspectives within climate research and policy settings (Hulme 2010; Klein et al. 2014; Offen 2014). Ethically, because climate impacts are experienced by individuals at local scales, many argue that non-expert voices and perspectives should play a larger role in efforts to measure and respond to these impacts (Burningham and O'Brien 1994; Brace and Geoghegan 2011). Scientifically, local knowledge can provide an important source of information on changes that are occurring in different communities/geographies where critical gaps in observational data and abilities to model climate parameters at fine scales (discussed in more detail below) exist (Turnbull 2002; Wilbanks 2002; Roth 2004; Laidler 2006). In cases where observations are scarce or unavailable, or where model results contradict one another, local knowledge can make a particularly important contribution to scientific knowledge and debates (Klein et al. 2014). Finally, from a practical perspective, understanding how people are experiencing, perceiving, and responding to climate variability and change is key to devising effective and locally appropriate adaptation and mitigation strategies (Becken et al. 2013; Yaro 2013). To the extent that local concerns are well aligned with observed or predicted changes coming from climate models, motivating action to respond to climate change will be easier, whereas a mismatch between expert and lay perspectives may inhibit action (Patt and Schröter 2008).

Within the social sciences, a wide range of methods exist for measuring the knowledge and perceptions of a target group or population (Huntington 2000; Pain 2004). These include qualitative methods, such as focus group discussions and in-depth interviews, which are typically used to provide detailed, narrative information about how a relatively small set of individuals thinks or views a problem (Huntington 2000). To date, most research on local perceptions of climate change has employed qualitative methods. For example, Yaro (2013) examined perceptions of climate change using focus group discussions and in-depth interviews with groups of small and commercial farmers in two communities in Ghana. Becken et al. (2013) studied local perceptions through a qualitative case study with 30 tourism stakeholder participants in the Annapurna Region of Lower Mustang, Nepal. While these methods are well suited for providing detailed knowledge and narratives among specifically targeted individuals or groups, they generally do not allow inferences about how prevalent certain perceptions are across a broader population. In contrast, quantitative social survey methods are an alternative way of measuring individuals' knowledge and perceptions (Huntington 2000). Questionnaires or surveys have the potential to provide more standardized information across a larger sample of individuals, and when that sample is randomly drawn from some larger population, results can be generalized to make inferences about that population. Quantitative surveys measuring climate perceptions are fairly common in developed country settings (Leiserowitz 2006; Brody et al. 2008). Fewer such surveys have been conducted in developing countries, though two particularly relevant studies assessed farmers' perceptions of climate change and their adaptation strategies in the Ashanti region of Ghana in 2008 and 2009 (Kemausuor et al. 2011; Fosu-Mensah et al. 2012).

Using meteorological records to examine local impacts

Efforts to use meteorological data to examine the local-scale impacts of climate variability and change have faced important challenges in developing countries (arguably where the need is greatest) due to a lack of long-term, reliable in situ meteorological records (Watson et al. 1998) For example, there are no meteorological stations in Northern Ghana with records extending beyond the year 1975 included in the monthly summaries of version three of the Global Historical Climatology Network (GHCN), a worldwide database of daily meteorological measurements from over 90,000 land-based stations that is widely used to detect recent climatic changes (Lawrimore et al. 2011). In lieu of having high-quality in situ meteorological information, researchers must interpolate to a given region of interest from large-scale gridded climatic datasets that may be derived from (1) kriging of nearby (or distant) land-based weather stations (Hijmans et al. 2005), (2) satellite radiances (Huffman et al. 2010), (3) atmospheric or land surface models (Monaghan et al. 2012), or (4) a combination of these techniques (Adler et al. 2003). Uncertainty within these global gridded datasets can be particularly large in data-sparse regions because in situ observations are often used to calibrate the datasets (Hijmans et al. 2005). Therefore, approaches that must use global gridded datasets to quantify local-scale climatic impacts in data-sparse regions may consider using numerous large-scale meteorological datasets for each variable of interest (i.e., temperature, precipitation) in order to characterize the uncertainty associated with the meteorological fields (Moore et al. 2012). This approach is used in the present study, in order to augment the single long-term meteorological record (albeit incomplete) from the region that was identified.

This study joins only a handful of prior studies to examine both local perceptions and meteorological data on recent weather and climate trends for the same geographic area (Roncoli et al. 2002; Yaro 2013; Shaffer 2014). Our methods for examining local perceptions involve a quantitative survey conducted with a representative sample of the population of the study area, such that our results allow us to infer the prevalence of different perceptions within that larger population. Furthermore, Global Positioning System (GPS) coordinates are available for study households, enabling us to examine variation in these perceptions across space. In addition, we conduct a meteorological analysis using the best available datasets for the West African region. While most long-term meteorological records from weather stations are incomplete or of unknown quality in this area, estimates of climate parameters (air temperature and precipitation) are obtained from multiple remotely sensed and modeled meteorological data sources, rather than relying on a single data source as is done in other studies (Yaro 2013). The results are used to inform a discussion of the challenges and opportunities involved in comparing local perceptions with climate data, and pathways forward for data collection and analysis that can help us build a more integrated understanding of the local impacts of global climate change.

Materials and methods

Study area

The study area is the Kassena and Nankana (K–N) Districts of the Upper East Region of Ghana in West Africa (Fig. 1).[1] The K–N Districts have a combined area of 1674 km^2 and a population of 159,758 (in 2013). The area is comprehensively characterized by Oduro et al. (2012). About 10% of the population lives in the central urban areas around Navrongo Town, while the rest of the population is primarily rural. Subsistence farming is the dominant activity for people in this area, with millet as the main crop. The regional land cover is a fairly even mix of cropland and savannah (ranging from open to dense trees), and a modest amount of wetland areas near water bodies. The Tono Dam is used for dry season farming, though most of the people do not have access to land within the irrigation area.

The region experiences a dry season from November to May and a wet season (during which crops are grown) from June to October. During the past three decades, near-surface temperatures over Ghana have increased by roughly 0.20–0.25 °C decade^{-1} during both the wet and dry seasons (Neumann et al. 2007; Trenberth and Fasullo 2013) and are projected to continue warming throughout the twenty-first century at a rate of about 0.25–0.35° decade^{-1} (Christensen et al. 2007). Rainfall over Sahelian Africa

---

[1] This was originally a single district but was split into two (Kassena-Nankana East and Kassena-Nankana West) in 2008. Data collection and analysis are based on the original combined district boundaries here.

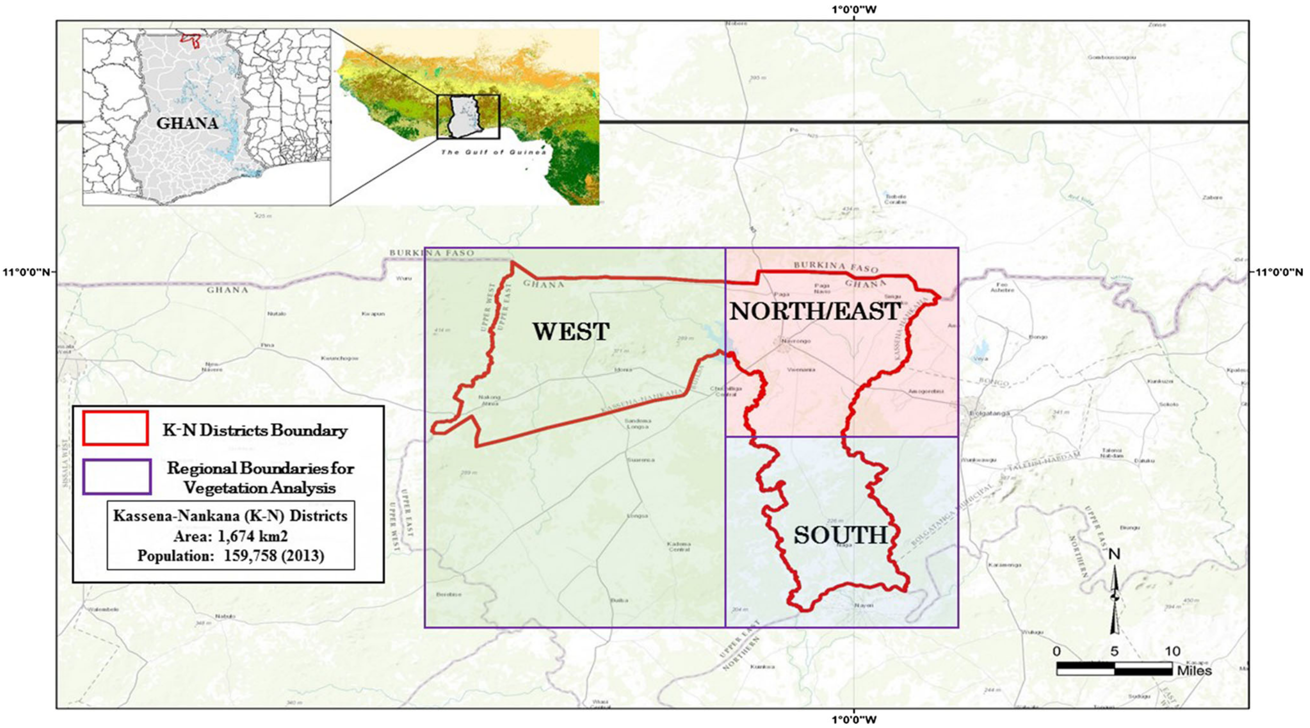

Fig. 1 Location of Kassena and Nankana Districts in Northern Ghana, and boundaries of regions used in vegetation analysis of Landsat images

exhibits strong variability at annual, decadal, and longer timescales, which makes elucidating long-term changes challenging (Nicholson 2000). Droughts occur frequently (Kasei et al. 2010) and floods are common, often with devastating effects (Armah 2010). Floods in Northern Ghana in August–September 2007, for example, resulted in a death toll of 20 people, loss of livestock, farmlands, homes, and other infrastructure (Armah 2010). Annual rainfall amounts in West Africa generally decreased during the latter decades of the twentieth century (Nicholson et al. 2000), before rebounding from the 1990s to present (Lebel and Ali 2009). Overall, weather records presented in a recent study in the Upper West Region of Ghana, adjacent to our study area, indicate that no statistically significant change in annual rainfall amounts occurred between 1953 and 2011 (Nyantakyi-Frimpong and Bezner-Kerr 2015). This finding corroborates an earlier study of weather records in the Volta Basin of West Africa, in which our study area resides, finding few stations with significant annual rainfall trends in recent decades, though among those stations reporting significant trends, most were negative (Neumann et al. 2007). There is evidence that the timing of the rainy season in the Volta Basin has shifted since the 1980s toward later onset dates and that the number of rainy days in Northern Ghana may be decreasing in both the wet and dry seasons (Laux et al. 2008). Future rainfall projections for the region are highly uncertain due to disagreement among climate models as to whether conditions will become drier or wetter (e.g., Haarsma et al. 2005; Held et al. 2005; Christensen et al. 2007), though the balance of studies suggest the future may be drier rather than wetter (Yaro 2013).

Survey-based perception data

Data on local perceptions of recent changes in weather and climate come from a survey of 200 households that was conducted at the outset of a study examining cooking practices in the K–N Districts. Cooking with biomass fuels, mainly over open fires, is the dominant practice in the largely rural population of this district. This practice has implications for human health, local and regional air quality, and global climate. These impacts motivated the randomized intervention study that was launched in these districts in November 2013 to examine the impacts of two improved cookstove technologies on a wide variety of social, physical, and health outcomes (Dickinson et al. 2015).

Study households were randomly selected from the district population that met three main criteria for study eligibility: Households were rural (90% of households in the district) and had at least one child under five (roughly 40% of households in the district) and one woman aged between 18 and 55 (about 80% of households in the district). Cluster random sampling was used to draw the study sample: First, 25 clusters (i.e., administrative groupings of

Table 1 Characteristics of survey respondents

Variable	Sample distribution $N = 200$
Region	
East	40 (20%)
North	48 (24%)
South	64 (32%)
West	48 (24%)
Respondent's age	
Mean	36.4
Median	34
Range	12–82
Respondent's education	
Never attended school	102 (51%)
Primary or lower	61 (32%)
Jr high/secondary	36 (18%)
Tertiary/higher	1 (.5%)
Respondent's occupation	
Agriculture/farming	109 (55%)
Trader/artisan	63 (32%)
Housewife	11 (6%)
Student	4 (2%)
Not working	6 (3%)
Other	7 (4%)
Head's occupation	
Agriculture/farming	145 (73%)
Trader/artisan	25 (13%)
Not working	11 (6%)
Other	19 (10%)
Household size	
Mean	8.3
Median	7.5
Range	3–26

25–99 household compounds) were drawn from the four rural regions of the K–N Districts (north, south, east, west), with the number of clusters per region selected in rough proportion to the population distribution across these regions, and then eight households meeting the eligibility criteria were randomly selected from each cluster. A baseline survey was conducted with all 200 households in November and December of 2013 prior to initiation of the cookstove intervention. Given the study's focus on cooking practices, households' primary cooks (all females in our sample) served as the survey respondents. Characteristics of sampled households and survey respondents are summarized in Table 1. Respondents ranged in age from 12 to 82 years, with a mean of 36.4. The majority of respondents (51%) had never attended school, while roughly a third had only attended primary school and less than one-fifth had completed junior high, secondary, or higher levels of education. Households were primarily agricultural, with the majority of both respondents (55%) and household heads (73%) listing farming as their main activity. Self-employment in trading or artisan activities was the second most common occupation among respondents (32%) and household heads (13%). It is important to keep these characteristics in mind in interpreting our results. Specifically, we note that the perceptions we are measuring are those of this particular subpopulation, i.e., rural women with young children in their households. These perspectives may differ from those of other groups, such as males in this region.

The hour-long survey covered a variety of topics including household composition and socioeconomics, priorities and challenges faced by households, cooking practices, knowledge and perceptions of environmental and health-related topics linked to cooking practices, and health measures. Surveys were conducted in one of the two local languages (Kasem or Nankam) by four experienced and extensively trained interviewers employed by the Navrongo Health Research Centre. The study protocol and all survey instruments were reviewed and approved by the Human Subjects Committee of the National Center for Atmospheric Research and the Institutional Review Board of the Navrongo Health Research Centre.

The knowledge and perceptions section of the survey contained two questions directly related to climate and weather variability. The question we primarily focus on in this paper asked, "What, if any, changes have you noticed in local weather patterns over the past several years?" This survey question was asked in an unprompted format: Interviewers did not read out response options to respondents, but listened to the answers that were given and then categorized them according to several pre-coded response options that were developed through several rounds of survey pretesting. (Multiple responses were permitted—e.g., "Hotter" and "Drier.") This response format retains many of the benefits of an open-ended survey question in that respondents are able to "think aloud" and provide answers in an unconstrained manner, while also facilitating quantitative data analysis and comparisons across a large number of respondents regarding the *most salient* changes that respondents are perceiving. However, we note that this method differs from that used in other studies (Kemausuor et al. 2011; Fosu-Mensah et al. 2012) in that we did not explicitly ask respondents to provide their assessment of changes in different climate parameters (temperature, rainfall amount, rain timing). We return to this point in discussing our results.

Following this question, respondents who noted any changes were asked why they thought these changes were occurring. This question was open-ended: Interviewers translated and recorded respondents' answers directly.

Responses were subsequently analyzed for common themes and coded (i.e., categorized into these different themes) by two researchers.

Meteorological Records

Reliable, long-term meteorological records from weather stations are not available in the K–N Districts for our 1979–2013 period of interest. However, a reasonably complete, quality-controlled record in the GHCN-Daily version 3 archive (Menne et al. 2012) is available for Po weather station in Burkina Faso, 30 km north of Navrongo, for the period 1983–2013. The station has 71% of monthly precipitation observations available over this period, and 98% of monthly temperature observations. We employ this station record, along with air temperature and precipitation estimates obtained from numerous gridded meteorological data sources based on satellite radiances, kriged records from weather stations within several 100 km of the district, atmospheric models, or a combination of these platforms. Though all of the meteorological datasets (including the weather station observations) are subject to methodological or measurement uncertainties that may limit their usefulness, by assessing multiple datasets side by side, we can evaluate whether consistent meteorological anomalies exist across datasets. If three to four datasets based on different methodologies exhibit similar temperature or precipitation anomalies, we can be reasonably confident that the results are robust. Aside from the Po weather station data, three additional temperature datasets and four additional precipitation datasets were used for this study. Additional information and citations on all datasets are provided in the Supplementary Material. These datasets were chosen because they had complete or nearly complete records since the late 1970s (the beginning of the modern satellite era and many model-based datasets). Data from each dataset (other than the Po weather station data) were bilinearly interpolated to the centroid of the K–N Districts, 10.76°N latitude, 1.17°W longitude.

Temperature and precipitation records were evaluated for the 35-year period spanning 1979–2013. The average monthly temperature anomalies and average monthly total precipitation were calculated for the entire 1979–2013 period, as well as the most recent 15 years (1999–2013), 10 years (2004–2013), 5 years (2009–2013), 3 years (2011–2013), 2 years (2012–2013), and 1 year (2013). Results were aggregated for the duration of the rainy (April–October) and the dry (November–March) seasons (note that the months defining end of the dry season and beginning of the rainy season are earlier by one month from the definition provided in the study area description section to emphasize the driest months of the dry season).

To obtain a longer-term perspective, we also assessed two drought indices: the Standardized Precipitation Index (SPI) and the Standardized Precipitation-Evapotranspiration Index (SPEI) for various time periods between 1950 and 2013. The SPI provides estimates of drought based on the normalized, accumulated precipitation over the past several months. The SPEI is similar, except that temperature data are used to estimate the impact of potential evapotranspiration, so that the SPEI can give a more comprehensive estimate of drought. Index values below zero indicate drier-than-normal conditions.

Remotely sensed data

To investigate temporal fluctuations in vegetation density—which may indicate deforestation—we also examined multispectral satellite imagery from Landsat for three periods: the 1990s, 2000s, and 2010s. The study area is at the intersection of four Landsat scenes, so to ensure complete clear-sky coverage, two days were used to represent each period: October 26, 1989, and October 12, 1990 (1990s period); September 22, 2000, and July 14, 2001 (2000s period); and October 20, 2013, and September 28, 2014 (2010s period). Landsat TM4-5 was used for the 1990s, Landsat ETM+ for the 2000s, and Landsat 8 for the 2010s. Once the clear-sky scenes were selected and combined for each of the three periods, the 30-m pixels in each scene were categorized into 10–15 land use classes using the ISO Unsupervised Classification Scheme in ArcGIS 10.3, informed by 6 multispectral channels: blue, green, red, near-infrared, and two short-wave infrared bands. Next, classes that represented dense, undisturbed vegetated areas were selected by comparing Landsat pixels to higher-resolution visible images from Google Earth. Dense vegetated areas were defined as having both dense forests and savannas (mixed trees and grasslands), with no obvious evidence of disturbances due to agriculture or other human activities. Dense vegetated areas were clustered similarly among the three time periods despite independently categorizing them for each period, indicating that the classification scheme is robust and consistent across time. Finally, all classes representing these dense, undisturbed vegetated areas were aggregated for each of the three periods and expressed as a percentage of total pixels across the study area, broken down by each region: west, south, and north/east (Fig. 1).

Results

Survey-based perception data

The survey was completed with 200 people in November–December 2013. Responses to the survey question that asked respondents about their perceptions of recent

Table 2 Survey responses to the question: "What, if any, changes have you noticed in local weather patterns over the past several years?"

Response	Overall $N = 200$		By region								
			East $N = 40$		North $N = 48$		South $N = 64$		West $N = 48$		p value
	#	(%)	#	(%)	#	(%)	#	(%)	#	(%)	
Changes in timing of rainy season/less predictable rains	84	42	10	25	25	52	25	39	24	50	0.04**
Drier/less rain	72	36	16	40	9	19	28	44	19	40	0.04**
Windier	53	27	6	15	14	29	6	9	27	56	0.00***
Hotter	36	18	4	10	14	29	10	16	8	17	0.11
Wetter/more rain	5	2.5									
Cooler	4	2.0									
No changes	7	3.5									
Other	3	1.5									
Don't know/not sure	15	7.5									

p values correspond to Chi squared tests of the null hypothesis that the percentage of respondents perceiving each change is equal across the four regions. * = $p < 0.1$, ** = $p<0.05$, *** = $p<0.01$

changes in weather patterns over the past several years are presented in Table 2. The two response categories mentioned most frequently both identified changes in precipitation: 42% of respondents perceived changes in the timing of the rainy season or the predictability of the rains, while 36% of respondents thought that the weather had become drier overall. Just over a quarter of respondents (26.5%) said that it had become windier, while just under one-fifth (18%) said that it had gotten hotter. Other responses (wetter, cooler, no changes) were noted by fewer than 5% of respondents, while 7.5% of respondents said they did not know what changes had occurred.

The four most common responses were analyzed by geographic subregions within the district. There is a moderate degree of spatial variation in the two responses related to precipitation patterns: Respondents in the east were somewhat less likely to note changes in rain timing, while respondents in the north were less likely to say that it was drier overall. More notable are the differences in perceived windiness: Table 2 shows that over 50% of respondents in the west mentioned increases in wind, while this change was noted by just 9% of respondents in the south. Supplementary Material includes maps that show how these responses vary at a finer spatial scale (i.e., geographic clusters of eight households). We observe a band of clusters in the west, north, and east in which large proportions of respondents perceived that it had become windier in the past several years.

Differences in perceived changes in weather were also analyzed by respondent and household characteristics, including respondents' age, education, and occupation. No significant differences across these groups were observed.

Respondents that mentioned any observed changes in weather and climate were asked why they thought these changes were occurring. A wide range of responses were given to this open-ended question. Based on the subsequent coding of these responses (i.e., categorizing responses into common themes), the most common response theme included explanations invoking acts of God or religion: About 30% of responses mentioned God in some way. This is similar to Yaro's (2013) finding that small farmers in Ghana tended to attribute changes in climate to social, moral, and religious causes. In our study, examples of responses in this category included:

> *God wants to punish us for our sins*
> *It is because we want to be greater than God.*
> *God has changed the weather for us.*
> *It is God's work.*

The second most common category of response regarding the causes of observed changes in weather patterns was deforestation. Of the 185 respondents who said they had noticed any weather changes, 52 (26%) included deforestation as a perceived cause of these changes. Examples of responses coded under this category included:

> *There are fewer trees today than in the past.*
> *Indiscriminate felling of trees.*
> *Cutting of trees for firewood and charcoal.*
> *Because of bush burning and tree cutting.*

We tabulated the proportion of cases in which deforestation was given as a cause for a specific type of weather change and found that deforestation was mentioned most frequently (46%) by respondents who said weather conditions had become drier. Deforestation was also mentioned by about a third of respondents that said conditions had become windier and also by a third of those perceiving hotter weather. This explanation was given less frequently (17%) by those noting changes in timing or predictability of rains.

We also examined differences in the proportion of respondents mentioning deforestation by region. In the west clusters, about 40% of respondents that observed any changes in weather patterns attributed these changes to deforestation, compared to 24% across the other three regions. This difference is statistically significant at the 5% level. It is noteworthy that the west is a more highly vegetated region than the other three regions (the exception being the far southern reaches of the south region, where there were no respondents).

"Global climate change" was not specifically mentioned as a cause of observed changes by any of our survey respondents, though it is important to note that responses were translated from the two local languages into English and that this phrase may not be readily transferable across languages. Sixteen responses (about 9%) were coded as referring to a "changing world." Some specific examples included:

> *God has changed the system.*
> *God has changed the weather for us.*
> *The world is changing.*
> *The world is changing because we have abandoned our culture.*

Even leaving language translation issues aside, these responses do not suggest that the narrative of global climate change is prevalent in this population.

Meteorological Records

Near-surface air temperature There is generally good agreement among the four analyzed temperature datasets, which all show that seasonal average temperature anomalies over most of the past 15 years have been warmer than the average of the past 35 years (Fig. 2, red and green bars). There is no evidence that temperatures over the past

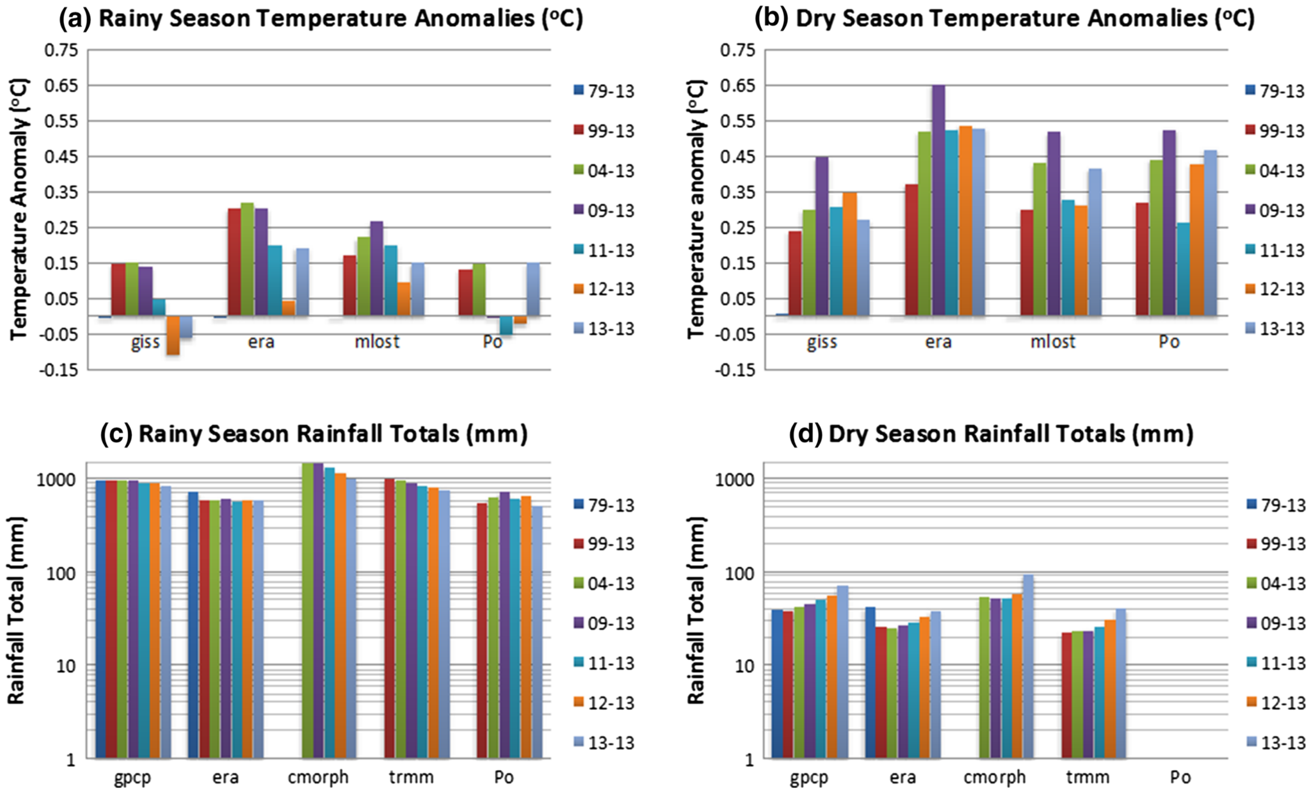

Fig. 2 Rainy season (April–October) and the dry season (November–March) average temperature anomalies (°C; *panels* a and b) and rainfall totals (mm; *panels* c and d) for the entire 1979–2013 period, as well as the most recent 15 years (1999–2013), 10 years (2004–2013), 5 years (2009–2013), 3 years (2011–2013), 2 years (2012–2013), and 1 year (2013). Temperature anomalies are with respect to the 1979–2013 mean (therefore, the "79–13" temperature anomalies are zero). Rainfall totals are plotted on a logarithmic scale to facilitate comparison between rainy and dry season amounts. Three rainfall records do not span the entire 1979–2013 period: CMORPH (2004–2013), TRMM (1999–2013), and Po (July 1983–2013). Dry season rainfall totals are not reported for Po because they are typically not reported

1–3 years have been warmer than that over the past 5–10 years, and during the rainy season, temperatures appear to have been cooler than or near the average for the past 5–15 years. Temperatures have increased most during the dry season, the time of year when low moisture availability means that most of the radiant energy from the sun and atmosphere is partitioned toward sensible heating (i.e., warming the atmosphere). Despite the fact that overall rainy and dry season temperatures during the most recent several years are not extraordinary, a noteworthy exception is that especially strong positive temperature anomalies have occurred during November over the past 3–5 years, which may influence the survey responses given that the surveys were administered in November 2013.

Precipitation and drought There is agreement among some of the gridded datasets that the rainy season (April–October) as a whole has been drier over the past 3–5 years compared to the past 10–35 years (Fig. 2). The results from the Po weather station are inconclusive; missing data during some rainy season months may confound assessing rainfall trends from the Po record (recall that only 71% of rainfall data are available from Po). Similar results (generally drier conditions in recent years) were noted when examining weekly rainfall data rather than monthly (not shown). It appears that the drier conditions have mainly been due to lower rainfall during the peak months of the rainy season, namely June and July. There is evidence in the weekly data (not shown) that the onset of the peak rainy season during the past 10 years has shifted later by about a month, from May to June. Dry season rainfall amounts are so small as to be negligible regardless of any shifts. Monthly values of the 3, 6 and 12 month drought indices suggest that recent drought conditions are not extraordinary within the past ~60 years, though 2013 appeared to have drier-than-normal conditions, especially for the 6- and 12-month timescales (not shown). The variability of rainfall at monthly, weekly, and daily timescales was also examined by calculating the standard deviations for each timescale across various time periods (not shown). We find that rainfall variability over the past 3–10 years has not been out of the ordinary, and if anything has been less variable during the peak rainy season months over the past 5 years, which is consistent with lower rainfall amounts during these months as noted above. However, looking at the year prior to the survey, it does appear that March of 2013 was wetter than the previous 3–5 years, while September of 2013 was drier than previous years.

Vegetation density Given that survey responses to the questions about perceived changes in windiness and deforestation varied spatially across the region, we compared vegetation density in the west, north/east and south regions over the past three decades (Fig. 3). We found that the percentage of dense vegetation—which is indicative of undisturbed forested and savannah areas—decreased between the 1990s and 2010s in all three regions, suggesting that a loss of fully or partially tree-covered areas occurred. The percentage decrease was particularly large in the west.

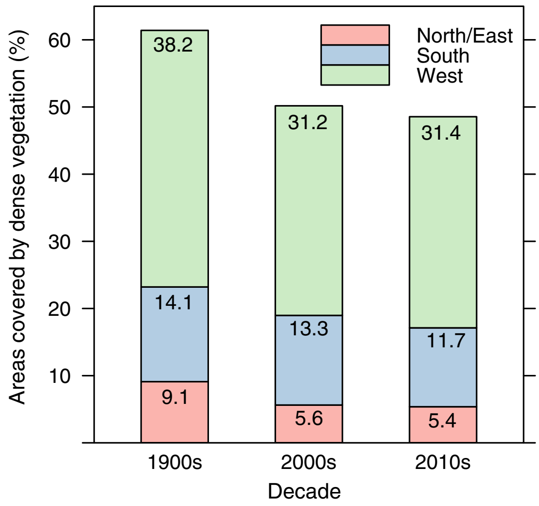

Fig. 3 Landsat-based assessment of deforestation, indicating the percentage of the total study area covered by dense vegetation from each region

Discussion

A comparison between the changes reported by respondents in our household survey and the trends detected through our analysis of meteorological data from the K–N Districts is summarized in Table 3. The most common weather change noted by respondents was to the timing or predictability of the rains: 42% of respondents provided a response that was coded by interviewers into this category. Our analysis of the weekly rainfall records indeed suggests that the onset of the peak rainy season has shifted progressively later, from May to June, over the past decade. However, during the year of the survey, there is evidence that rains started slightly earlier than normal (in March), while later season (September) rains were less than previous years. Therefore, the meteorological records agree with respondents that the onset of the rainy season has been more variable during recent years. Both types of data also agree that conditions have become drier in the area overall. This change was the second most frequently mentioned among survey respondents (36% of respondents), and three of five of the meteorological data sources analyzed showed a clear trend of less precipitation during the rainy season over the past 3–5 years.

The correspondence between perceptions and meteorological data trends is more variable for other parameters. Examining our temperature results, fewer than 20% of respondents thought that conditions in the area had become

Table 3 Comparison of local perceptions and meteorological data

Climate variable	Perceptions	Trends in data	Comparison
Temperature	Hotter Perceived by 18% of respondents overall No significant spatial variation	Past 15 years warmer than 35-year average, but overall rainy and dry season temps not extraordinary during most recent 1–3 years	Mixed results depending on time frame considered. Perception that it has become hotter is less prevalent in population than other perceived changes
Precipitation	Drier Perceived by 36% of respondents overall Lower in north versus other regions	Rainy season (April–October) likely drier over the past 3–5 years compared to the past 10–35 years, mainly due to lower rainfall during peak months (June and July)	Agreement between data and perceptions on overall drier conditions
	Changes in timing/variability of rains Perceived by 42% of respondents overall Higher in north and west versus south and east	The onset of the peak rainy season has shifted progressively later over the past decade, by up to a month. No evidence of increased variability of rainfall	Agreement between data and perceptions on shift in rain timing
Winds	Windier Perceived by 27% of respondents overall Higher in west	No reliable datasets available	N/A
Land cover	Deforestation Mentioned as cause of climate changes by 26% of respondents noting any change Higher in west	Dense vegetation (including trees) decreased in all three regions between 1990 and 2014, particularly in the west	Agreement between data and perceptions on deforestation; inconclusive as to whether this contributed to local climatic change

hotter. This is a somewhat surprising result, as the meteorological data clearly indicate a robust warming trend over the past 15 years compared to the past 35 years. However, temperatures during the most recent three years were no warmer than during the past 5–15 years, suggesting that the warming trend has leveled off over the past decade, which would be consistent with the global warming "hiatus" since 2000 (e.g., Trenberth and Fasullo 2013). Meanwhile, changes in windiness perceived by about a quarter of respondents could not be compared with any existing meteorological datasets for the study area.

Perceived changes in land cover (deforestation) were corroborated by repeat Landsat image analysis between 1990 and 2014. The imagery indicated that the overall percentage of dense vegetation—indicative of undisturbed areas fully or partially covered with trees—decreased from 61.4% of the total study area (all regions combined) in the 1990s to 48.5% of the total study area by the 2010s. The heavily vegetated west region accounted for about half of the total loss, decreasing from 38.2 to 31.4% of the total study area. The west is also the region where the highest proportion of respondents, 40%, perceived deforestation as a cause of recent weather changes, suggesting that perceptions match observations even within each region. We were not able to confirm whether land cover changes such as deforestation contributed to observed changes in weather patterns; such an analysis is beyond the scope of this study.

There are a number of factors that may account for observed discrepancies between local knowledge of perceived climatic changes and the meteorological analyses conducted for this region. First, we recognize that the specific data sources used in this study have limitations that affect our ability to make comparisons between perceptions and meteorological data. To begin with, we are using responses measured at a single point in time (November/December of 2013), and the primary survey question we analyze here asks respondents about changes they have observed over the "past several years." Because the survey wording is somewhat imprecise, it is not clear what relevant timeframe respondents had in mind in responding to this question. We account for this to some extent by examining the meteorological data using different time periods (e.g., past 3 vs past 5 years), but this does not account for the fact that different respondents may have interpreted the question in different ways. It is unclear whether respondents would be able to give more specific answers if the question were phrased more precisely. For example, would respondents be able to recall or differentiate perceptions about changes in the most recent year versus the most recent three years? This question deserves further inquiry.

Moreover, our survey question was posed using an unprompted format that likely elicited the perceived changes that respondents found most salient or relevant. In contrast, other studies have explicitly asked respondents whether, for example, they believed temperatures were increasing, decreasing, or staying the same (Kemausuor et al. 2011; Fosu-Mensah et al. 2012). These studies' results, albeit from a few years earlier than ours (2008 and 2009) and in a different region of Ghana, indicated higher proportions of respondents perceiving increasing temperatures (82 and 92% in the two studies). Fosu-Mensah et al. (2012) also found that 87% of respondents perceived decreasing precipitation, while Kemausuor et al. (2011) used somewhat different precipitation response options and found that 93% of respondents perceived changes in rain timing. While it is insightful to know which changes respondents find relevant enough to mention without prompting, we acknowledge that the more specific questions used in these studies have the benefit of eliciting perceptions on each parameter from every respondent, facilitating some comparisons with meteorological data.

A related issue arises in the case of the most commonly mentioned perceived weather change, which included changes in the "timing of rainy season/less predictable rains." The use of an unprompted survey response format for this question means that many different verbatim answers could be assigned to each pre-coded answer. In this case, it is not entirely clear what respondents meant by "less predictable," making it difficult to assess whether the meteorological data show a similar trend to what respondents were perceiving. Survey questions and response options could be developed to be more precise and more closely match the quantities measured in the meteorological data. For example, separate pre-coded response categories could be provided for changes in the *timing* of rains versus perceived changes in *predictability* or variability of the rains across time. Another example of a possible question that could be used to quantify perceptions differently would ask respondents how rainfall in the past month compares to past years at the same time of year. Comparing responses to such a question with meteorological data would be more straightforward since there would be less potential for differences in the interpretation of the question across respondents. Furthermore, since people may be more likely to remember specific events rather than average conditions, both survey questions and meteorological analyses could focus on extremes such as droughts, heat waves, and floods.

In addition, as noted previously, the analyzed meteorological data were mostly from large-scale datasets that provide estimates of temperature, rainfall, and vegetation parameters. The one reasonably complete weather station record we identified, from nearby Po 30 km to the north of Navrongo, had temperature results similar to the large-scale datasets, but precipitation results were questionable due to missing data. While the use of multiple meteorological datasets can help assess uncertainty regarding local changes in temperature and precipitation, it is still likely that additional scale-related uncertainty due to local microclimatic and land use effects is present. Better in situ monitoring for climate baselines and trends would help to address this shortcoming. Local observations of winds would enable further examination of the perception that winds are increasing, particularly in certain areas of the region.

We also reiterate that our particular survey captures weather and climate perceptions from one particular subpopulation within the K–N Districts: rural women. It is quite likely that other subpopulations (e.g., men, urban dwellers) could have different perceptions of climate variability and change. Fully representing the perceptions of the entire population would require examining and accounting for these differences. Future work will compare the perceptions of this rural sample in the K–N to those of a recently completed survey of a representative sample of urban households in this same district.

In addition to the specific limitations of data used in this study, it is important to acknowledge that inherent differences between local knowledge and meteorological data imply that even if both were measured perfectly, it is quite possible that substantial differences would persist between them. For example, while an analysis of meteorological data can uncover statistical features and trends for certain parameters by weighting all data points equally, perceptions are likely to be more heavily weighted toward recent or more memorable events (Tversky and Kahneman 1973; Mertz et al. 2009). Thus, abnormally high temperatures during the month that the survey was conducted may have influenced some respondents' perceptions about overall hotter conditions, although by this rationale, it is somewhat surprising that the perception of warming temperatures was not more widespread. It may also be the case that some climate parameters are easier to directly observe than others. Rainfall timing and amounts may be more easily observable and quantifiable in this area than other climate parameters such as temperature, particularly given the heavy reliance of the population on rain-fed agriculture. This could account for the relatively strong concordance between perceived and measured changes in predictability and trends in drying. More generally, this discussion highlights the fact that local perceptions and meteorological records may be measuring fundamentally different constructs, such that trying to assess which of this data sources is most "accurate" is likely less useful than working toward using both sources in a complementary way.

Conclusion

In order to more fully understand and respond to the local impacts of global climate change, a variety of perspectives and data sources will need to be incorporated and integrated. Bringing local knowledge into this discussion engages perspectives which have historically been "uncounted" or deemed "unscientific" within Western science (Hulme 2008; 2010). Ultimately, we agree with Klein et al. (2014) that "local knowledge does not exist to be confirmed or disproved by Western science, but rather can also advance Western science and help contribute to its debates" (p. 141). In this study, we found many areas of concordance between perceptions and scientific observations, pointing toward potential areas in need of policy action. In the K–N Districts, adaptation strategies for addressing later rainy season onset and drier conditions should be examined, particularly given that this is an area heavily dependent on rain-fed agriculture. Further assessment of the impacts of and possible responses to deforestation in this area is also recommended. Meanwhile, areas of disagreement between these different types of data highlight possible directions for further study using diverse methods.

Moving forward, collection of both social science and meteorological data on climate impacts could incorporate some degree of "citizen science" and participatory methods in order to ensure that data collection and analysis are not disconnected from people's reality on the ground (Irwin 1995; Elwood 2008; Alexander et al. 2011). Volunteers from the same population who provided their perceptions of recent weather changes could be recruited to collect measurements of temperature, precipitation, and extreme weather events (WMO 2001). The resulting process of knowledge co-production (Berkes 2009) can help to fill gaps within more "scientific" datasets as a means to inform locally appropriate policy. Incorporating local knowledge in this way contributes to what Hulme (2010) calls a "cosmopolitan perspective" to global environmental change which "allows local and situated knowledge about multi-scale environmental changes to become globally visible." Such an approach also responds to a broadening focus of global change research. While questions about global-scale changes in climate parameters may rely heavily on meteorological data, understanding which climate-related challenges are most pressing within specific communities requires local perspectives. These latter questions are at the forefront of environmental change research and policy.

Acknowledgements The authors would like to acknowledge funding sources for the project, the National Science Foundation (Grant # GEO–1211668) and the US Environmental Protection Agency (Grant # RD–8354201). NCAR is sponsored by the National Science Foundation.

References

Adler RF, Huffman GJ, Chang A, Ferraro R, Xie P-P, Janowiak J, Rudolf B, Schneider U, Curtis S, Bolvin D (2003) The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979-present). J Hydrometeorol 4(6):1147–1167. doi:10.1175/1525-7541(2003)004%3C1147:TVGPCP%3E2.0.CO;2

Alexander C, Bynum N, Johnson E, King U, Mustonen T, Neofotis P, Oettlé N, Rosenzweig C, Sakakibara C, Shadrin V (2011) Linking indigenous and scientific knowledge of climate change. Bioscience 61(6):477–484. doi:10.1525/bio.2011.61.6.10

Armah FA, Yawson DO, Yengoh GT, Odoi JO, Afrifa EKA (2010) Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. Water 2(2):120–139. doi:10.3390/w2020120

Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) (2014) IPCC, 2014: Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press

Becken S, Lama AK, Espiner S (2013) The cultural context of climate change impacts: perceptions among community members in the Annapurna Conservation Area, Nepal. Environ Dev 8:22–37. doi:10.1016/j.envdev.2013.05.007

Berkes F (2009) Indigenous ways of knowing and the study of environmental change. J R Soc N Z 39(4):151–156. doi:10.1080/03014220909510568

Berkes F (2012) Sacred ecology. Routledge, New York

Brace C, Geoghegan H (2011) Human geographies of climate change: Landscape, temporality, and lay knowledges. Prog Hum Geogr 35(3):284–302. doi:10.1177/0309132510376259

Brody SD, Zahran S, Vedlitz A, Grover H (2008) Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. Environ Behavior 40(1):72–95. 10.1177/0013916506298800

Burningham K, O'Brien M (1994) Global environmental values and local contexts of action. Sociology 28(4):913–932. doi:10.1177/0038038594028004007

Christensen JH, Hewitson B, Busuioc A,Chen A, Gao X, Held R, Jones R, Kolli RK, Kwon W, Laprise R (2007) "Regional climate projections." Climate change, 2007: the physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press: Cambridge, Cambridge, Chapter 11: 847–940

Dickinson KL, Kanyomse E, Piedrahita R, Coffey E, Rivera I, Adoctor J, Aligiria R, Muvandimwe D, Dove M, Dukić V, Hayden M, Diaz-Sanchez D, Adoctor V, Anaseba D, Slichter YC-H, Masson N, Monaghan A, Titiati A, Steinhoff D, Hsu Y-Y, Kaspar R, Brooks B, Hodgson A, Hannigan M, Oduro AR, Wiedinmyer C (2015) Research on emissions, air quality, climate, and cooking technologies in Northern Ghana (REACCTING): study rationale and protocol. BMC Public Health 15(1):126. doi:10.1186/s12889-015-1414-1

Elwood S (2008) Volunteered geographic information: future research directions motivated by critical, participatory, and feminist GIS. GeoJournal 72(3–4):173–183. doi:10.1007/s10708-008-9186-0

Fosu-Mensah BY, Vlek PL, MacCarthy DS (2012) Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. Environ Dev Sustain 14(4):495–505. doi:10.1007/s10668-012-9339-7

Goldman M (2007) Tracking wildebeest, locating knowledge: maasai and conservation biology understandings of wildebeest behavior in Northern Tanzania. Environ Plan D: Soc Space 25(2):307. doi:10.1068/d0505

Haarsma RJ, Selten FM, Weber SL, Kliphuis M (2005) Sahel rainfall variability and response to greenhouse warming. Geophys Res Lett 32(17):L17702. doi:10.1029/2005GL023232

Held I, Delworth T, Lu J, Findell KU, Knutson T (2005) Simulation of Sahel drought in the 20th and 21st centuries. Proc Natl Acad Sci USA 102(50):17891–17896. doi:10.1073/pnas.0509057102

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25(15):1965–1978. doi:10.1002/joc.1276

Huffman GJ, Adler RF, Bolvin DT, Nelkin EJ (2010) The TRMM multi-satellite precipitation analysis (TMPA). Satellite rainfall applications for surface hydrology. Springer, New York, pp 3–22

Hulme M (2008) Geographical work at the boundaries of climate change. Trans Inst Br Geogr 33(1):5–11. doi:10.1111/j.1475-5661.2007.00289.x

Hulme M (2010) Problems with making and governing global kinds of knowledge. Global Environ Change 20(4):558–564. doi:10.1016/j.gloenvcha.2010.07.005

Huntington HP (2000) Using traditional ecological knowledge in science: methods and applications. Ecol Appl 10(5):1270–1274. doi:10.1890/1051-0761(2000)010%5B1270:UTEKIS%5D2.0.CO;2

Irwin A (1995) Citizen science: a study of people, expertise, and sustainable development. Routledge, New York

Kasei R, Diekkrüger B, Leemhuis C (2010) Drought frequency in the Volta basin of West Africa. Sustain Sci 5(1):89–97. doi:10.1007/s11625-009-0101-5

Kemausuor F, Dwamena E, Bart-Plange A, Kyei-Baffour N (2011) Farmers' perception of climate change in the Ejura-Sekyedumase district of Ghana. ARPN J Agric Biol Sci 6(10):26–37

Klein JA, Hopping KA, Yeh ET, Nyima Y, Boone RB, Galvin KA (2014) Unexpected climate impacts on the Tibetan Plateau: local and scientific knowledge in findings of delayed summer. Global Environ Change 28:141–152. doi:10.1016/j.gloenvcha.2014.03.007

Laidler GJ (2006) Inuit and scientific perspectives on the relationship between sea ice and climate change: the ideal complement? Clim Change 78(2–4):407–444. doi:10.1007/s10584-006-9064-z

Laux P, Kunstmann H, Bárdossy A (2008) Predicting the regional onset of the rainy season in West Africa. Int J Climatol 28(3):329–342. doi:10.1002/joc.1542

Lawrimore JH, Menne MJ, Gleason BE, Williams CN, Wuertz DB, Vose RS, Rennie J (2011) An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3. J Geophys Res 116:D19121. doi:10.1029/2011JD016187

Lebel T, Ali A (2009) Recent trends in the Central and Western Sahel rainfall regime (1990–2007). J Hydrol 375(1):52–64. doi:10.1016/j.jhydrol.2008.11.030

Leiserowitz A (2006) Climate change risk perception and policy preferences: the role of affect, imagery, and values. Clim Change 77(1–2):45–72. doi:10.1007/s10584-006-9059-9

Menne MJ, Durre I, Vose RS, Gleason BE, Houston TG (2012) An overview of the global historical climatology network-daily database. J Atmos Oceanic Technol 29(7):897-910. doi:10.1175/JTECH-D-11-00103.1

Mertz O, Mbow C, Reenberg A, Diouf A (2009) Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. Environ Manag 43(5):804–816. doi:10.1007/s00267-008-9197-0

Monaghan AJ, MacMillan K, Moore SM, Mead PS, Hayden MH, Eisen RJ (2012) A regional climatography of West Nile, Uganda, to support human plague modeling. J Appl Meteorol Climatol 51(7):1201–1221. doi:10.1175/JAMC-D-11-0195.1

Moore SM, Monaghan A, Griffith KS, Apangu T, Mead PS, Eisen RJ (2012) Improvement of disease prediction and modeling through the use of meteorological ensembles: human plague in Uganda. PLoS ONE 7(9):e44431. doi:10.1371/journal.pone.0044431

Neumann R, Jung G, Laux P, Kunstmann H (2007) Climate trends of temperature, precipitation and river discharge in the Volta Basin of West Africa. Int J River Basin Manag 5(1):17–30. doi:10.1080/15715124.2007.9635302

Nicholson SE (2000) The nature of rainfall variability over Africa on time scales of decades to millenia. Global Planet Change 26(1):137–158. doi:10.1016/S0921-8181(00)00040-0

Nicholson SE, Some B, Kone B (2000) An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. J Clim 13(14):2628–2640. doi:10.1175/1520-0442(2000)013%3C2628:AAORRC%3E2.0.CO;2

Nyantakyi-Frimpong H, Bezner-Kerr R (2015) The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. Global Environ Change 32:40–56. doi:10.1016/j.gloenvcha.2015.03.003

Oduro AR, Wak G, Azongo D, Debpuur C, Wontuo P, Kondayire F, Welaga P, Bawah A, Nazzar A, Williams J (2012) Profile of the navrongo health and demographic surveillance system. Int J Epidemiol 41(4):968–976. doi:10.1093/ije/dys111

Offen K (2014) Historical geography III climate matters. Prog Hum Geogr 38(3):476–489. doi:10.1177/0309132513501429

Orlove B, Roncoli C, Kabugo M, Majugu A (2010) Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. Clim Change 100(2):243–265. doi:10.1007/s10584-009-9586-2

Pain R (2004) Social geography: participatory research. Prog Hum Geogr 28:652–663. doi:10.1191/0309132504ph511pr

Patt AG, Schröter D (2008) Perceptions of climate risk in Mozambique: implications for the success of adaptation strategies. Global Environ Change 18(3):458–467. doi:10.1016/j.gloenvcha.2008.04.002

Riedlinger D, Berkes F (2001) Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. Polar Record 37(203):315–328. doi:10.1017/S0032247400017058

Roncoli C, Ingram K, Kirshen P (2002) Reading the rains: local knowledge and rainfall forecasting in Burkina Faso. Soc Nat Res 15(5):409–427. doi:10.1080/08941920252866774

Roth R (2004) Spatial organization of environmental knowledge: conservation conflicts in the inhabited forest of northern Thailand. Ecol Soc 9(3):5. doi:10.5751/ES-01186-090305

Shaffer LJ (2014) Making sense of local climate change in rural Tanzania through knowledge co-production. J Ethnobiol 34(3):315–334. doi:10.2993/0278-0771-34.3.315

Trenberth KE, Fasullo JT (2013) An apparent hiatus in global warming? Earth's Future 1(1):19–32. doi:10.1002/2013EF000165

Turnbull D (2002) Performance and narrative, bodies and movement in the construction of places and objects, spaces and knowledges the case of the Maltese Megaliths. Theory Culture Soc 19(5–6):125–143. doi:10.1177/026327602761899183

Tversky A, Kahneman D (1973) Availability: a heuristic for judging frequency and probability. Cogn Psychol 5(2):207–232, doi:10.1016/0010-0285(73)90033-9

Watson RT, Zinyowera MC, Moss RH (1998) The regional impacts of climate change: an assessment of vulnerability. Cambridge University Press, Cambridge

Wilbanks TJ (2002) Geographic scaling issues in integrated assessments of climate change. Int Assess 3(2–3):100–114. doi:10.1076/iaij.3.2.100.13575

WMO (2001) Volunteers for weather, climate and water. World Meteorological Organization, Geneva, p 919

Yaro JA (2013) The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. Reg Environ Change 13(6):1259–1272. doi:10.1007/s10113-013-0443-5