Unrealized Potential: A Review of Perceptions and Use of Weather and Climate Information in Agricultural Decision Making

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(Manuscript received 17 December 2012, in final form 23 July 2013)

ABSTRACT

This article reviews research on agricultural decision makers' use and perceptions of weather and climate information and decision support tools (DSTs) conducted in the United States, Australia, and Canada over the past 30 years. Forty–seven relevant articles, with locations as diverse as Australian rangelands and the southeastern United States, ranging in focus from corn to cattle, were identified. NVivo 9 software was used to code research methods, type of climate information explored, barriers to broader use of weather information, common themes, and conclusions from each article. Themes in this literature include the role of trusted agricultural advisors in the use of weather information, farmers' management of weather risks, and potential agricultural adaptations that could increase resilience to weather and climate variability. While use of weather and climate information and DSTs for agriculture has increased in developed countries, these resources are still underutilized. Reasons for low use and reduced usefulness highlighted in this literature are perceptions of low forecast accuracy; forecasts presented out of context, reducing farmers' ability to apply them; short forecast lead times; inflexible management and operations that limit the adaptability of a farm; and greater concern with nonweather risks (such as regulation or market fluctuation). The authors' main recommendation from reviewing this literature is that interdisciplinary and participatory processes involving farmers and advisors have the potential to improve use of weather and climate DSTs. The authors highlight important gaps revealed by this review, and suggest ways to improve future research on these topics.

1. Introduction

A significant body of research supports the potential value of increasingly sophisticated and accurate weather and climate forecasts for applications such as agricultural production (Ash et al. 2007; Hansen 2002; Livezey and Timofeyeva 2008; Palmer and Anderson 1994; Quan et al. 2006; Westra and Ashish 2010). While there is still room to improve forecast skill, weather forecasts, climate information, and decision support tools (DSTs) can help the agricultural sector reduce weather and climate impacts (Ash et al. 2007; Hansen 2002; Livezey and Timofeyeva 2008; Quan et al. 2006; Westra and Ashish 2010). However, these weather resources need to be designed and delivered in ways that promote farmers' willingness and ability to use them to aid in agricultural decision making.

A substantial amount of social science research has been conducted on aspects of use and perceived usefulness of weather and climate information as tools for farmers, and in some cases their advisors, to improve the resilience of agriculture in the face of increasing climate variability and change. This systematic review brings together the most relevant research conducted in industrialized countries (including the United States, Australia, and Canada, as no studies from other industrialized countries met criteria for inclusion) to combine findings and draw conclusions about farmers' and advisors' perceptions and use of weather and climate information and barriers to broader or improved use of information and tools in developed countries.

Over the past decade, there have been some efforts to synthesize this literature or similar literature in various regions and countries. These include a review by Roncoli (2006) of ethnographic and participatory research on farmers' perceptions of weather and climate forecasts in both the developed and developing world, which highlighted barriers to broader application of weather and climate forecasts to agriculture, especially

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DOI: 10.1175/WCAS-D-12-00062.1

in developing countries. Ash et al. (2007) review studies concerning the potential of El Niño–Southern Oscillation (ENSO)-based seasonal climate forecasts (SCFs) for multiple sectors of Australian agriculture, emphasizing the need for improved forecast skill and communication of technical information to agricultural decision makers. Garbrecht and Schneider (2007) discuss research on improving and delivering climate models, forecasts, and tools for U.S. agriculture and explore the merits of top-down versus participatory approaches to both forecast delivery and development of applied weather information for farmers—concluding that top-down approaches are more appropriate for modeling and improving forecast skill, while participatory approaches are more important for the delivery of weather forecasts and information. Bryant et al. (2000) reviewed research on adaptation to climate change in Canadian agriculture, including at the farm, community, provincial, and national level without specifically addressing farmers' use of climate information or forecasts. In Australia, Power et al. (2007) address what they argue are important barriers to broader application of seasonal and interannual climate forecasts in agriculture around the world. Meinke and Stone (2005) focus on the potential of seasonal and interannual climate forecasts in Australia, emphasizing that climate forecasts are not a "silver bullet" to weather impacts but rather one tool that can be used in certain situations to manage risks. Similar to Garbrecht and Schneider (2007), they argue for more participatory research that considers farmers' perspectives as well as cross-disciplinary approaches that bring together climate, agricultural, and social science to make the most of advances in forecasting (Meinke and Stone 2005). Hansen (2002) reviews research up to that time on the potential of climate forecasts for agriculture in both the United States and Australia, what weather and climate information farmers are currently using, and what types of information and tools they wanted to see in the future.

While these reviews have shed light on some issues in forecast application to agriculture in the developed world, there has not been a comprehensive review of applied social science research that synthesizes farmers' and advisors' perceptions of weather and climate forecasts, information, and tools as well as their use of these resources to adapt to risks from climate variability. Sonka et al. (1992) highlight the importance of applied social science research, noting that "Many prior analyses of climate prediction use have tended to be speculative studies of possible applications without sampling users…" (p. 1999). In this review, we bring together both quantitative and qualitative applied studies to further our understanding of why many farmers in the developed world are not using climate forecasts and tools for weather risk management. Forecast and DST developers can examine our analysis of this literature to increase the usability of their products for agricultural adaptation to climate variability and change.

This systematic review is focused on agriculture in developed or more industrialized countries, where farmers may have higher adaptive capacity (including financial capacity) and skill at using climate information, forecasts, and decision support tools than farmers in many developing countries (Roncoli 2006). To make the most of the management advantages offered by weather and climate information, it is critical to understand if, why, and how agricultural decision makers are using these tools. In addition, this review will discuss the role of farmers' perceptions of risk from climate variability, as covered in the literature, and relationships with their willingness to use forecasts and tools to manage their farms. This review also covers research on farmers' and advisors' preferences for particular characteristics and formats of climate information in these countries. Additionally, this article provides an overview of barriers to effective application of weather information to agriculture that should be addressed to realize the potential of forecasts. Finally, we discuss gaps in the literature noted by others and highlight areas that require further study.

2. Research questions

We began this systematic review with the following research questions (RQ):

RQ1: From this literature, what are developed world farmers' perceptions of climate forecasts and DSTs? How do farmers and their advisors think these could be applied in agricultural decision making?

RQ2: What have existing studies found about how and why farmers and advisors in the developed world use or do not use weather/climate forecasts and DSTs to make decisions?

RQ3: What are the strengths and weaknesses of this literature, and how can future research better contribute to our understanding of these issues?

3. Methods

Searches for relevant key words (farmers, agriculture, climate, weather, use, forecast, information, etc.) were conducted through Google Scholar (http://scholar.google.com/) to identify peer-reviewed articles for inclusion in this review. There are additional resources on farmer perceptions and use of weather and climate information in non-peer-reviewed forms, such as reports prepared by the Southeast Climate Consortium (SECC). However, for consistency we include only peer-reviewed journal articles in this review.

This article focuses on applied studies conducted in developed/industrialized countries. The main reason for the focus on more developed/industrialized nations was to facilitate the generation of broad coherent themes and comparisons across studies and across contexts with similar economic and social background factors. Including research conducted in developing nations would have made it difficult to justify drawing out common themes from this literature. Second, the focus allowed the scope of the review to remain manageable, as there seem to have been more studies on use and perceptions of weather forecasts throughout the developing world than in the most industrialized nations. We included studies utilizing an applied social science component to understand farmers and/or their advisors, and excluded those with a purely theoretical focus. In addition, research had to address farmers' and/or advisors' use (or nonuse) of climate information or perceptions of a forecast or DST to be included. The bibliographies of relevant articles were then examined to identify additional potential articles to include. Finally, reverse citation searches on Google Scholar [e.g., 130 articles have cited Hansen (2002)] were used to find more articles that fit within the frame for this review. A majority of studies fitting these criteria were conducted in the United States and Australia, with some additional relevant studies based in Canada. No studies from Europe fit the criteria for inclusion in this review. Overall, 47 articles were included in this review, and Table 1 below gives an overview of these articles and demonstrates the range of contexts where farmers' and advisors' perceptions or use of weather and climate information have been investigated.

This review differs from traditional meta-analysis, since the body of literature contains a significant amount of qualitative research, such as interviews and focus groups, in addition to more quantitative studies that utilized surveys and modeling. Using QSR NVivo 9 qualitative software, relevant information from each article was coded, including study location, research methodology, agricultural sector, farmers' or advisors' perceptions of climate information/forecasts/DSTs, and measured use of climate information or forecasts by farmers or advisors. Emergent themes, such as important barriers to broader use of climate information and decisions/adaptations that could potentially be informed by forecasts/DSTs were also coded. Two researchers analyzed articles for this review. Initially, each researcher individually and independently coded nine articles for the presence of factors/themes, and then compared codes. Percent agreement was calculated to be 74.6%. Where there was disagreement between coders, the researchers discussed the differences until agreement was reached, and then each proceeded to code a subset of the remaining articles.

4. Results/discussion

a. *Overview of findings*

Through our analysis of this literature published over the past 30 years, we were able to answer our research questions about agricultural decision makers' perceptions and use of climate and weather information, forecasts, and DSTs. Variables and themes emerging from this literature included measured and hypothesized barriers to optimal application of weather/climate information and tools to agriculture, farmers' and advisors' perspectives on useful information, adaptations that farmers could make by using weather and climate forecasts, as well as aspects of the research itself—such as whether a participatory approach to forecasts/DST development was used or advocated. As shown below in Table 2, most studies focused on if and how farmers use climate information and/or forecasts and discussed barriers that are reducing farmers' use of forecasts/DSTs in their decision making. Although not all of the articles measured use, 28 studies measured and/or discussed farmers' perceptions of climate information/forecasts/DSTs.

Advisors to farmers are less studied than farmers themselves, with only 12 articles addressing advisors' perceptions, or use of climate information and tools, and factors limiting their utilization. Types of agricultural advisors studied included university extension, private crop consultants, and agribusinesses, such as seed dealers. Most of the included articles also discussed farmer and/or researcher perspectives on potential applications for climate information in agriculture and possible climate change adaptation options that could be informed by climate forecasts or tools.

More than half of the articles (28) emphasized the challenges of communicating with farmers and/or advisors about weather and climate information, and/or offered recommendations about how to improve communication on these topics. About 40% of the articles (18) relied upon participatory research or advocated participatory development of weather or climate tools to increase the likelihood that farmers will actually use the information to inform decisions. Benefits of participatory processes for weather and climate tool development were discussed in this literature, especially in

TABLE 1. Articles included in review.

Author(s)	Publication year	Methodology	Location	Type of climate information	Type of agriculture
Artikov et al.	2006	Survey, regression analysis	Nebraska, United States	Weather and climate information and forecasts	Row crops, corn
Ash et al.	2007	Literature review: Potential of SCFs for agriculture	Australia	ENSO SCFs	Row crops, wheat, livestock
Breuer et al.	2008	Sondeo discussions, survey, testing a tool or system	Florida, United States	ENSO SCFs	Row crops, livestock
Breuer et al.	2009	Overview of participatory approaches in development of decision support system	Southeastern United States	ENSO SCFs	Mainly row crops, livestock
Cabrera et al.	2008	Interviews, focus groups, surveys, participatory model/tool development	Florida, United States	ENSO SCFs	Dairy farms
Cabrera et al.	2006	Interviews, focus groups, sondeo discussions, testing a tool or system	Florida, United States	ENSO SCFs	Dairy farms
Cabrera et al.	2007	Modeling/simulation	Florida, United States	ENSO SCFs	Peanuts, cotton, corn
Carberry et al.	2002	Interviews, survey, modeling/simulation, participatory model/tool development	Australia	ENSO SCFs	Grains, cotton
Carlson	1989	Survey—farmers, extension, and agricultural professionals	Michigan, United States	Weather information	Row crops, fruits, vegetables, livestock
Changnon	2004	Multiple studies: Interviews, survey, decision experiments with agribusinesses	United States (nationwide)	Weather and climate predictions/forecasts, ENSO SCFs	Chemical manufacturers, seed producers, pest management, etc.
Changnon et al.	1987	Survey, testing a weather information system	Illinois, United States	Weather and climate information	Government agencies, agribusinesses, and farmers
Changnon et al.	1988	Interviews and survey with agribusiness firms	Midwestern United States	Weather and climate information	Processor, seed corn production company, agrichemical producer
Crane et al.	2010	Ethnographic interviews	Georgia, United States	ENSO SCFs, weather and climate information	Various, mostly row crops, produce, cattle
Crimmins et al.	2007	Focus group, survey, participatory model/tool development	Southwestern United States	Weather and climate predictions and information	Rangeland cattle
Dinon et al.	2012	Survey	North Carolina, United States	ENSO SCFs	Extension agents
Easterling	1986	Survey of subscribers to NOAA monthly and seasonal weather outlook, multivariate analysis	Nationwide, United States	Weather and climate predictions/forecasts	Farmers and agribusiness
Everingham et al.	2002	Modeling/simulation case studies, participatory model/tool development	Queensland, Australia	ENSO SCFs	Sugarcane
Frisvold and Murugesan	2013	Survey	Arizona, United States	Weather and climate information/data	Row crop farmers and ranchers
Furman et al.	2011	Survey, interviews	Georgia, United States	ENSO SCFs	Organic
Garbrecht and Schneider	2007	Review, modeling/simulations, testing a tool or system	United States	ENSO SCFs	Various

TABLE 1. (*Continued*)

Author(s)	Publication year	Methodology	Location	Type of climate information	Type of agriculture
Getz	1978	Survey of farmers, interviews with advisors/agribusinesses	New Jersey, United States	Weather forecasts and information	Fruits and vegetables
General Accounting Office	1979	Survey—farmers, extension agents, agribusinesses	United States (nationwide)	Weather forecasts and information	Grains, livestock, dairy, pasture
Hansen	2002	Literature review: Farmers' use and suggestions for more useful forecasts, participatory tool development	Florida, United States; Australia	Weather and climate predictions/forecasts, ENSO SCFs	Various
Hansen et al.	2004	Mental models interviews with farmers and climate experts	Florida, United States	Weather forecasts, ENSO SCFs	Fruits and vegetables
Hartmann et al.	2002	Informal discussions with potential users, participatory model/tool development, forecast evaluation	Southwestern United States	ENSO SCFs	Rangeland cattle
Hu et al.	2006	Focus groups and survey	Nebraska, United States	Weather and climate information and forecasts	Corn and other row crops
Jagtap et al.	2002	Rapid rural surveys, case studies, developing and testing models/tools	Florida, United States	ENSO SCFs	Tomatoes, peanuts, cattle
Jochec et al.	2001	Focus group, forecast decision scenarios, ecological–economic modeling	Texas, United States	ENSO SCFs	Rangeland cattle
Keogh et al.	2004	Survey, evaluation informing DST development	Queensland and New South Wales, Australia	ENSO SCFs	Livestock graziers—cattle and sheep
Keogh et al.	2005	Informal conversations with farmers, survey, rating potential forecast systems/DSTs	Western Australia	ENSO SCFs	Grazing industry—cattle and sheep
Marshall et al.	2011	In-person survey	Queensland, Australia	ENSO SCFs	Rangeland cattle
McCown et al.	2012	Longitudinal interviews with farmers and consultants, participatory model/tool development	Australia	Seasonal climate information and crop models/simulations	Corn, sorghum, wheat
McCrea et al.	2005	Judgment analysis/decision scenarios, survey, regression analysis	Queensland, Australia	ENSO SCFs	Dryland crops
McNew et al.	1991	Survey	Oklahoma, United States	Weather information and forecasts	Row crops, cattle, wheat
Meinke and Stone	2005	Review of simulation models research and additional simulation of forecast value	Australia	ENSO SCFs, interannual climate forecasts	Various row crops
Nelson et al.	2002	Participatory model/tool development and evaluation	Australia	ENSO SCFs	Grains, wheat, peanuts
Power et al.	2007	Review of advancements in climate modeling and application to agriculture	Australia	ENSO SCFs, and interannual climate forecasts	N/A
Prokopy et al.	2013	Survey	Midwestern United States	Weather information and forecasts	Advisors to corn/soy producers
PytlikZillig et al.	2010	Participatory model/tool development and evaluation, surveys, focus groups	Nebraska, United States	Weather and climate information and forecasts	Corn and other row crops

TABLE 1. (*Continued*)

Author(s)	Publication year	Methodology	Location	Type of climate information	Type of agriculture
Reid	2009	Model/tool development and training	Australia	Weather and climate change information	Row crops, livestock
Reid et al.	2007	Qualitative interviews, focus groups	Canada	Weather and climate change information	Row crops, dairy, livestock
Roncoli	2006	Literature review	United States, and others	Weather and climate information, ENSO SCFs	Various
Sonka et al.	1982	Survey, yield modeling, regression analysis	Illinois, United States	Weather and climate information and forecasts	Corn
Sonka et al.	1992	Interviews, survey of agribusinesses	United States	Climate forecasts	Seed producers, chemical dealers, crop consultants, crop/weather insurance
Tarnoczi and Berkes	2010	Qualitative interviews	Alberta and Manitoba, Canada	Climate change adaptation information	Grains
Vining et al.	1984	Survey—farmers and ranchers	Texas, United States	Weather and climate information	Wheat, cotton, cattle
Weiss and Robb	1986	Survey—top farmers	Western Nebraska, United States	Weather and climate information and forecasts	Wheat

those published in the last decade. Twelve studies highlighted farmer preferences for, as well as potential benefits and constraints of, using the Internet as a medium for communication of weather and climate information. Frisvold and Murugesan (2013) made the important point that while wealthier farmers with larger operations tend to have Internet access and use online resources in managing their farm, this is not necessarily the norm for smaller-scale and lower-income farmers.

b. *Social–psychological factors affecting farmers' perceptions and use of climate information*

This literature brings to light a variety of social–psychological factors that play an important role in the incorporation of weather and climate forecasts into agriculture. One challenge for developers of forecasts and DSTs is helping farmers cope with uncertainty and prepare for variability by providing information that they will actually use. An issue established in the literature is the disconnect between timing of available weather and climate information and when farmers are making decisions (Ash et al. 2007; Changnon 2004; Furman et al. 2011; Keogh et al. 2005; McNew et al. 1991; Sonka et al. 1982, 1992). If forecasts about a given growing season are not available or able to accurately predict conditions until after a farmer has made a key decision, they cannot be effectively utilized and incorporated in decision making. Another longstanding factor highlighted in this literature is how farmers deal with uncertainty and weather variability when managing their business/farm, and also variation in farmers' ability to interpret probabilities and uncertainty as a part of weather and climate forecasts (Breuer et al. 2008, 2009; Cabrera et al. 2008; Changnon et al. 1988; Crane et al. 2010; Everingham et al. 2002; Garbrecht and Schneider 2007; Getz 1978; Hansen 2002; Jagtap et al. 2002; Keogh et al. 2004, 2005; McCrea et al. 2005; Meinke and Stone 2005; Power et al. 2007; Roncoli 2006).

Farmers' perceptions of the risk to their farms from weather/climate variability is another issue affecting how they consider and use climate and weather information. Hansen (2002) points out that ''The primary motivation for individual farmers is an awareness of some level of vulnerability to impacts of climate variability, and opportunity to reduce that vulnerability through appropriate use of forecasts information'' (p. 312). Fifteen articles included some discussion of how farmers manage or minimize risks to their operations from weather or climate variability (see Table 2). Crane et al. (2010) found that farmers know they cannot avoid all weather-related risks to their farm operation, and thus ''employ management strategies ensuring some yield during most years and under most conditions. . . .

TABLE 2. Main themes and variables in this literature.

Theme/variable	No. of articles that measured and/or discussed	Articles that measured and/or discussed
Farmers' perceptions of weather or climate information and forecasts (usefulness, importance, etc.)	28	Artikov et al. 2006; Breuer et al. 2008, 2009; Cabrera et al. 2006, 2008; Carlson 1989; Changnon et al. 1987; Crane et al. 2010; Crimmins et al. 2007; Easterling 1986; Frisvold and Murugesan 2013; Furman et al. 2011; GAO 1979; Getz 1978; Hansen et al. 2004; Hartmann et al. 2002; Hu et al. 2006; Jochec et al. 2001; Keogh et al. 2004, 2005; Marshall et al. 2011; McCown et al. 2012; McCrea et al. 2005; McNew et al. 1991; PytlikZillig et al. 2010; Reid et al. 2007; Vining et al. 1984; Weiss and Robb 1986
Farmers' use of weather or climate information and forecasts and/or barriers/ reasons for low use	31	Artikov et al. 2006; Breuer et al. 2008, 2009; Cabrera et al. 2006; Carberry et al. 2002; Carlson 1989; Changnon et al. 1987; Crane et al. 2010; Crimmins et al. 2007; Easterling 1986; Everingham et al. 2002; Frisvold and Murugesan 2013; Furman et al. 2011; GAO 1979; Getz 1978; Hansen et al. 2004; Hartmann et al. 2002; Hu et al. 2006; Jagtap et al. 2002; Keogh et al. 2004, 2005; Marshall et al. 2011; McCown et al. 2012; McCrea et al. 2005; McNew et al. 1991; Nelson et al. 2002; PytlikZillig et al. 2010; Reid et al. 2007; Reid 2009; Vining et al. 1984; Weiss and Robb 1986
Advisors' perceptions, use of weather or climate forecasts/ information, and/or barriers to use	12	Carberry et al. 2002; Carlson 1989; Changnon et al. 1987, 1988; Crane et al. 2010; Dinon et al. 2012; GAO 1979; Getz 1978; McCown et al. 2012; Nelson et al. 2002; Prokopy et al. 2013a; Sonka et al. 1992
Potential adaptations or applications of weather and climate information/ forecasts to agriculture	26	Breuer et al. 2008; Cabrera et al. 2006, 2008; Carberry et al. 2002; Carlson 1989; Changnon et al. 1988; Dinon et al. 2012; Everingham et al. 2002; Frisvold and Murugesan 2013; Furman et al. 2011; GAO 1979; Hartmann et al. 2002; Hu et al. 2006; Jagtap et al. 2002; Jochec et al. 2001; Keogh et al. 2004, 2005; McCown et al. 2012; McCrea et al. 2005; McNew et al. 1991; Nelson et al. 2002; Prokopy et al. 2013a; Reid et al. 2007; Reid 2009; Sonka et al. 1982; Weiss and Robb 1986
Utilized or advocated participatory weather forecast/decision support tool development	18	Breuer et al. 2008, 2009; Cabrera et al. 2006, 2008; Carberry et al. 2002; Crane et al. 2010; Everingham et al. 2002; Garbrecht and Schneider 2007; Hansen 2002; Hartmann et al. 2002; Jagtap et al. 2002; Keogh et al. 2004, 2005; Meinke and Stone 2005; McCown et al. 2012; Nelson et al. 2002; Roncoli 2006; Sonka et al. 1992
Focusing weather risk events (drought, hurricane, etc.)	10	Carlson 1989; Changnon et al. 1987; Crane et al. 2010; Crimmins et al. 2007; Hansen et al. 2004; Hartmann et al. 2002; Jagtap et al. 2002; McNew et al. 1991; Reid et al. 2007; Sonka et al. 1982
Farmers' minimizing and managing climate/ weather risks	15	Cabrera et al. 2008; Crane et al. 2010; Everingham et al. 2002; Frisvold and Murugesan 2013; Hansen et al. 2004; Jochec et al. 2001; Keogh et al. 2004, 2005; Marshall et al. 2011; McCown et al. 2012; McNew et al. 1991; Nelson et al. 2002; Reid et al. 2007; Reid 2009; Tarnoczi and Berkes 2010
Challenges and recommendations for effective communication of weather and climate information	28	Breuer et al. 2008; Cabrera et al. 2008; Carlson 1989; Changnon 2004; Crane et al. 2010; Crimmins et al. 2007; Everingham et al. 2002; Frisvold and Murugesan 2013; Furman et al. 2011; GAO 1979; Getz 1978; Hansen et al. 2004; Hartmann et al. 2002; Jagtap et al. 2002; Keogh et al. 2004, 2005; Marshall et al. 2011; McCown et al. 2012; McNew et al. 1991; Nelson et al. 2002; Power et al. 2007; Prokopy et al. 2013a; PytlikZillig et al. 2010; Reid et al. 2007; Roncoli 2006; Sonka et al. 1992; Tarnoczi and Berkes 2010; Weiss and Robb 1986
Preference for communicating/sharing climate information via the Internet	12	Breuer et al. 2008; Carberry et al. 2002; Crane et al. 2010; Dinon et al. 2012; Furman et al. 2011; Hansen et al. 2004; Hartmann et al. 2002; Jagtap et al. 2002; Keogh et al. 2004, 2005; PytlikZillig et al. 2010; Reid et al. 2007

The rationale for this approach is that consistency eventually pays off and. . . it is safer than trying to adjust cropping patterns seasonally to maximize short-term gain'' (p. 50). As shown in Table 2, 10 articles discussed weather risk events (droughts, hurricanes, ice storms, and other extreme weather events that were experienced over the short term) that focused attention and influenced attitudes toward climate change/variability and risk management behaviors. Several articles explored how farmers view weather risks in economic terms, such as potential financial losses due to more variable precipitation, as well as the potential economic benefits of improved forecasts—particularly providing a competitive advantage in a global marketplace (Crane et al. 2010; Frisvold and Murugesan 2013; Jagtap et al. 2002; Marshall et al. 2011; McCrea et al. 2005; Meinke and Stone 2005; Nelson et al. 2002; Reid 2009; Tarnoczi and Berkes 2010).

A few articles (Furman et al. 2011; Marshall et al. 2011; Reid et al. 2007) highlighted the importance of social capital, arguing that when farmers have limited social capital it is more difficult for them to learn about new forecasting technologies and tools through informal interactions with other farmers. Crane et al. (2010) found that social networks were crucial for the dissemination and processing of information by farmers, often through social gatherings, more formalized farmer meetings, as well as business interactions with agricultural suppliers and brokers. Similarly, Artikov et al. (2006) and Hu et al. (2006) examined the role of perceived social norms in the decision to adopt new technologies or allow weather forecasts to influence decision making. Through multiple regression analysis, Artikov et al. (2006) and Hu et al. (2006) found that social norms had a significant influence on farmers' use of weather information to make decisions, especially agronomic decisions. Another motivator for farmers discussed in the literature was being able to observe new practices implemented by other farmers and a resulting decrease in perceived financial risk (Tarnoczi and Berkes 2010; Marshall et al. 2011). Tarnoczi and Berkes (2010) conducted interviews with Canadian farmers about climate change adaptation and found support for the ''diffusion of innovations'' framework (Rogers 2003) since ''Information that was observable or experiential was more significant for the adoption of new practices. For example, farmers claimed to be more willing to try conservation tillage techniques after seeing a neighbour succeed with the practice, even when they already had prior information on it'' (p. 303).

Trust—in the credibility, accuracy, and source of information as well as in advisors or consultants—influences farmers' perceptions and use of climate and weather forecasts and tools. The concepts of trust and source credibility are important in communication, especially when the source intends to persuade the audience to change their attitudes and/or behaviors, such as convincing farmers to use weather and climate information to inform decisions (Renn and Levine 1990). Hu et al. (2006) point out that farmers were skeptical of forecasts that contradicted one another, especially when it was unclear who or what organization had produced each forecast. Hansen et al. (2004) found an almost even split in confidence or lack of confidence in forecasts among Florida farmers. According to Marshall et al. (2011), most rangeland ranchers heard predictions of drought frequently, which lead them to be skeptical of when to take a prediction seriously after experiencing ''false warnings.'' The importance of trusted advisors or consultants who could help DST developers reach farmers and work with farmers to interpret climate information were addressed in a few of the articles. Trusted sources and potential outreach partners included family or business partners (Keogh et al. 2004), other farmers (Furman et al. 2011), Extension agents (Breuer et al. 2008, 2009; Cabrera et al. 2008; Dinon et al. 2012; Jagtap et al. 2002), climate scientists, and private agronomists and consultants (Carberry et al. 2002).

Collaborative approaches to developing forecasts and DSTs and participatory research stand out as an important strategy in this literature. As noted above in Table 2, more than a third of the included articles either utilized a participatory approach to tool development or advocated for more participatory processes and research endeavors. Bartels et al. (2013) describe in more detail the structure of the SECC participatory process that fostered two-way interactions between farmers, extension agents, and university researchers around climate change adaptation strategies. Asking for farmers' input early in the process and seeking feedback throughout can allow farmers to feel a sense of ownership over tools and have more favorable attitudes toward adaptation options recommended by forecasts or DSTs. This ''buy in'' or sense of ownership can improve farmers' and advisors' perceptions of climate information and tools and is a promising strategy to increase their use (Breuer et al. 2009; Cabrera et al. 2008; Hansen 2002; Jagtap et al. 2002; Meinke and Stone 2005; Nelson et al. 2002; Reid 2009). Overall, this literature shows the promise of social science for understanding social psychological determinants of favorable attitudes and use of weather and climate information and forecasts.

c. *Useful information for agricultural decision making*

Several of the articles in this review asked farmers and/or their advisors about weather or climate information that has been or would be useful for agricultural decision making. Hartmann et al. (2002) point out that the most useful aspect of a forecast is likely to vary with the type of decision a farmer is making. For example, farmers in Georgia emphasized the importance of shorter-term weather information (such as for the next week), which they already use and may check on a daily basis during the growing season, relative to longer-term forecasts (monthly or seasonal outlooks) that were perceived to have lower accuracy (Crane et al. 2010). Rangeland managers in the southwestern United States are a promising audience for decision support tools, since they are already using historical precipitation information (73%) and seasonal precipitation forecasts (69%) to make decisions (Crimmins et al. 2007). Changnon (2004) reviewed his previous research on U.S. farmers and advisors including agricultural chemical manufacturers, finance companies, pest management consultants, etc., that measured their use of forecasts and found that ''usage of climate predictions for general background information grew from 1981 to 1999, as did usage for making specific decisions'' (p. 611). Similarly, Dinon et al. (2012) found that North Carolina Extension agents agree that predictions about the weather for the upcoming growing season would be helpful.

Regarding what information agricultural decision makers would like access to, Crimmins et al. (2007) found that southwestern U.S. ''land managers' needs for climate information [go] beyond traditional statistical averages. Needs appear to include information on potential changes to the likelihood, frequency, and duration of climate and weather extremes, important in long-term planning to reduce vulnerability to climate change'' (p. 85). Similarly, some research revealed that farmers wanted forecasts that could accurately predict extreme weather events (Easterling 1986; Sonka et al. 1992). In Australia, agricultural consultants preferred applied ''what does this mean?'' information presented in combination with crop models rather than weather conditions or forecasts by themselves. In an interview, one Australian agricultural consultant said, ''There is no point knowing how much water you've got in your profile if you don't know what it means to your risk profile, or your cropping potential, if you like. Knowing what that level is is one thing, but knowing what it means is another thing. . . . That's where crop models come in'' (McCown et al. 2012, p. 37). Similarly, Hansen et al. (2004) found that Florida farmers wanted more applied information about how El Niño and La Niña would impact temperatures, especially winter lows. Together, these findings indicate that there is significant room to better combine and package weather and climate information and forecasts to suit the needs of agriculturalists.

Not surprisingly, several studies found that farmers and/or advisors would like to see improved forecast skill or reliability. Crane et al. (2010) found that while farmers were more likely to rely on short-term forecasts (such as 5-day weather forecasts) than seasonal climate forecasts, they did not completely trust this information to always be relevant and accurate. Many studies concluded that farmers want contextualized, location-specific forecast information to facilitate decision making on their own farms (Artikov et al. 2006; Breuer et al. 2008; Carberry et al. 2002; Carlson 1989; Changnon 1988, 2004; Crane et al. 2010; Furman et al. 2011; Hansen 2002; Hu et al. 2006; Keogh et al. 2005; McNew et al. 1991; Nelson et al. 2002; PytlikZillig et al. 2010; Roncoli 2006; Weiss and Robb 1986). While certain parameters, such as precipitation, may be difficult to predict at very local scales, forecasts and information can still be tailored to be more relevant to the context of a particular agricultural sector (i.e., frost forecasts for Florida fruit growers) (Westra and Ashish 2010). Additionally, they would like access to forecasts at the correct time to facilitate decisions (such as predicted harvest conditions) and predict impacts, so they can be mitigated before they become severe (Changnon 2004; Hansen 2002). While some of the characteristics that farmers want may be beyond the scope or ability of current forecasts, these findings point out areas where forecasts and tools can be improved and strive to achieve in the future. This literature also highlights current gaps between producers' desires and what modelers and forecasters have provided thus far.

d. *Agricultural adaptations that could be informed by climate forecasts/tools*

Most of the articles in this review presented scientists', advisors', and/or farmers' opinions about how climate forecasts or DSTs could be used to aid climate adaptation decision making. Potential uses for agronomic decisions ranged from changing crops and crop varieties (Crane et al. 2010), determining stocking rates for rangeland livestock (Keogh et al. 2004, 2005), choosing whether or not to plant winter forage for cattle (Jagtap et al. 2002), and deciding if/when to plough sugar cane (Everingham et al. 2002) to Australian wheat farmers using the Southern Oscillation index (SOI) as an indication of increased rainfall and deciding to plant early to benefit from improved growing conditions (Nelson et al. 2002). Ash et al. (2007) argue that utilizing forecasts proactively to take advantage of favorable conditions may be more important for agriculture than using them to prepare for poor growing conditions. Furman et al. (2011) described how organic farmers, often with more flexible operations than conventional farmers, make initial plans around available 10-day forecasts, and then when short-term forecasts and additional data were available they could modify their management activities and decisions if needed. Several articles touched on the potential for farmers to reduce economic risks or increase their competitive advantage in increasingly international markets by using climate or weather forecasts. They also noted farmers' interest in weather conditions in other regions of the world that are producing the same crops and how conditions will affect commodity prices (Changnon 2004; Crane et al. 2010; Hansen 2002; Meinke and Stone 2005). Hartmann et al. (2002) heard informally from discussions with farmers that they are interested in how competitors might use forecasts, but remained skeptical of their value owing to perceived low accuracy. Overall, the research conducted thus far points to several avenues for improved weather and climate forecasts and DSTs to aid farmers in adapting to climate change.

e. *Barriers limiting farmers' use of climate information*

Many of the articles emphasized underutilization of weather and climate forecasts in agriculture relative to their potential (Ash et al. 2007; McCown et al. 2012). For example, Marshall et al. (2011) point out that, although Australian rangeland cattle ranchers ''showed interest in the economic and environmental benefits and costs of seasonal climate forecasts, only 40% of graziers in our study were highly likely to adopt the [SCF] technology once it becomes available to the region'' (p. 522). More than half of the articles discussed barriers to optimal use of climate information or tools by farmers. Some studies asked farmers or their advisors directly, while others drew inferences from other data about why climate information, forecasts, and tools are underutilized by farmers in the developed world. Barriers to use fell into three broad categories: aspects of the forecast itself (such as skill, scale, and lead time), farmers and advisor perceptions (such as interpretation/understanding, risk from weather/climate, and urban bias), and contextual factors (such as inflexible operations, market fluctuations, and lack of resources).

The most commonly cited barrier, especially in more recent research, was farmers' or advisors' perceptions of low accuracy of forecasts/models and their concern that predictions and information were not provided on a local enough scale to be useful (Artikov et al. 2006; Breuer et al. 2008; Cabrera et al. 2008; Carberry et al. 2002; Changnon et al. 1988; Crane et al. 2010; Dinon et al. 2012; Easterling 1986; Hansen et al. 2004; Hartmann et al. 2002; Hu et al. 2006; Keogh et al. 2005; Marshall et al. 2011; McCrea et al. 2005; Power et al. 2007; Sonka et al. 1992; Vining et al. 1984; Weiss and Robb 1986). Farmers' lack of understanding or awareness of available climate information was addressed in 10 articles (Cabrera et al. 2006; Changnon et al. 1988; Crane et al. 2010; Furman et al. 2011; Getz 1978; Keogh et al. 2004, 2005; Reid et al. 2007; Sonka et al. 1992; Vining et al. 1984). Through interviews in Florida, Hansen et al. (2004) found that farmers were not aware of their misconceptions in terms of weather and climate information and forecasts; in other words, they ''don't know what they don't know,'' and this overconfidence may reduce their motivation to understand forecasts more thoroughly.

Seven studies from the late 1970s through early 1990s found that the types of weather information that farmers indicated would be useful were unavailable in their main sources of weather information—public television and radio forecast—and that short forecast lead times impeded use (Carlson 1989; Changnon et al. 1988; Easterling 1986; GAO 1979; Getz 1978; McNew et al. 1991; Sonka et al. 1992). Easterling (1986) concluded that the lack of climate prediction lead time was the most important barrier to broader use of the National Oceanic and Atmospheric Administration (NOAA)'s monthly and seasonal weather outlook. A more recent study by Keogh et al. (2005) discussed how very short forecast lead times made it difficult for rangeland graziers to utilize weather information in decision making. These authors cite research from Africa conducted by Ingram et al. (2002), which suggested that ''a less skillful forecast issued with sufficient lead time may be more valuable than a highly skillful forecasts that arrives at a time when a producer's decision cannot be revoked'' (Keogh et al. 2005, p. 1614). The specific preferred lead time varied depending on the study and within studies between different types of agricultural production and different decisions that had potential to be informed by weather and/or climate information, but was generally on the scale of a month to a few months. On a similar note, Crane et al. (2010) reported that farmers perceived an ''urban bias'' in forecasting, meaning that television stations tailor their weather information to cities rather than rural areas where agriculture occurs. A report by the GAO (1979) found that farmers preferred forecasts tailored to agriculture rather than forecasts designed for the general public.

Eight articles cited fixed or inflexible management, operations, or resource conditions as constraints on farmers' use of climate information and forecasts (Breuer et al. 2008; Cabrera et al. 2006; Crane et al. 2010; Furman et al. 2011; Hansen 2002; Hu et al. 2006; Jagtap et al. 2002; Marshall et al. 2011). Greater concern with issues other than weather or climate risks, such as government regulation and market fluctuations, was noted in seven articles (Artikov et al. 2006; Breuer et al. 2008; Cabrera et al.

2008; Crane et al. 2010; Jagtap et al. 2002; Tarnoczi and Berkes 2010; Weiss and Robb 1986). Five articles discussed limitations posed by tools or forecasts that are too difficult or complicated to use, or require the help of an expert to interpret (Carberry et al. 2002; Garbrecht and Schneider 2007; Keogh et al. 2004, 2005; Power et al. 2007). Five of the included articles discussed that farmers or advisors did not recognize a problem that could be addressed with climate/weather information or tools (Cabrera et al. 2006, 2008; Carberry et al. 2002; Dinon et al. 2012; Reid et al. 2007) and five mentioned farmers' aversion to new technology or change (Breuer et al. 2008; Cabrera et al. 2006; Changnon et al. 1988; Marshall et al. 2011; Reid et al. 2007). A related barrier was that some farmers remained unconvinced that changing decisions based on climate information would lead to improved agricultural outcomes (Changnon 2004; Marshall et al. 2011; Power et al. 2007; Roncoli 2006). In at least one study, farmers believed that others would benefit more from weather information: "Several farmers stated that other stakeholders, such as chemical suppliers, insurance companies, brokers, relief agencies, and banks, might benefit more from climate forecasts than would agricultural producers" (Breuer et al. 2008, p. 394).

A few articles identified government financial assistance, through crop insurance and other programs, as reducing incentives to adapt to climate variability and at times limiting farmers' flexibility through strict requirements (Cabrera et al. 2007; Crane et al. 2010; Jagtap et al. 2002). An additional barrier is that farmers are making decisions in the short term, rather than the long term, and short-term decisions do not always require or benefit from seasonal climate forecasts or longer-term planning and adaptation tools (Cabrera et al. 2006; Roncoli 2006). Several studies found that farmers preferred and relied on short-term forecasts, such as 24 h or 5 day, rather than longer-term forecasts, suggesting that farmers are engaging in more short-term decision making (Breuer et al. 2008; Crane et al. 2010; Hansen et al. 2004; McNew et al. 1991; Weiss and Robb 1986). Two articles mentioned the high cost of recommended adaptations as a potential disincentive for utilizing weather forecasts and tools for adaptation planning (Breuer et al. 2008; Cabrera et al. 2006). A related barrier is that farmers planning to retire soon and not expecting children or other family to continue the operation are not motivated to make investments in new technologies or long-term risk management strategies, including those that would improve their farms' adaptability to climate change (Reid et al. 2007).

There is an extensive literature on the potential of climate forecasts/DSTs for agriculture in developing countries, which we felt was too large and diverse to synthesize in this review of developed countries. Some general areas of overlap that could be further explored include preferences for contextualized and localized weather/climate information (Ash et al. 2007; Roncoli 2006) and the importance of timing of accurate forecasts before farmers make decisions, which can be one to six months in advance (Luseno et al. 2003; McIntosh et al. 2005). The importance of source credibility for climate information was highlighted for agricultural decision makers in developing countries as well as developed (Ingram et al. 2002). Another concept that was relevant in both the developing and developed world was the potential and importance of participatory approaches to weather/climate tool development (Gadgil et al. 2002; Patt et al. 2005; Podesta et al. 2002).

f. Strengths of existing research

Overall, this literature provides good coverage of seasonal climate forecast use, particularly in the southeastern United States and Australia. Collectively, these studies have explored a variety of issues with SCF use in a variety of agricultural contexts in these regions. Participatory decision support tool development processes have also been the subject of thorough study that describes the strengths and challenges of conducting them in each of these regions, and a case is made for the continued use of participatory processes to increase the use and effectiveness of climate DSTs in agriculture.

Our analysis leads us to conclude that involving farmers, researchers, advisors, and other agricultural stakeholders in the development of DSTs can have numerous benefits. Benefits of participatory processes highlighted in this literature include providing each stakeholder group with a more holistic view of the agricultural system, allowing participants to recognize common ground for improved communication, and improved adaptation to climate change as farmers face additional environmental regulations and economic hurdles (Cabrera et al. 2008). As Breuer et al. (2009) point out, the participatory process around the development of AgroClimate, a decision support system (DSS) for the southeastern United States, has led to higher awareness and broader distribution, and "Overall, participation enhances legitimacy of the project" (p. 9). Roncoli (2006) and Cabrera et al. (2008) caution that participatory research approaches have the potential to "introduce biases" into a product if they are not conducted with a representative population and could lead to tools that meet the needs of one group or subgroup more than other stakeholders, so we agree they should be used alongside additional "comparative and complementary methodologies to ensure consistency and integrity in the whole process'' (Cabrera et al. 2008, p. 405).

One distinction worth noting is that some of the studies in this review measured actual use of climate information or DSTs by farmers and advisors, while other studies examined farmers' or advisors' perspectives on potential use/usefulness in the future. This distinction between research studies has implications for how results from these different studies can be interpreted. Understanding current use is most helpful for determining which available information and tools are working and which are not for farmers' present needs. However, there is also value in understanding what the agricultural community perceives as potential uses for weather and climate information in the future. As long as these potential uses for weather or climate information are proposed by intended end users, there is a role for this information in future research and DST development. Future studies should continue to solicit this type of feedback from farmers and advisors in order to highlight applications and uses that forecasters and tool developers may not have considered.

g. *Evolution of and gaps in this literature: Improving future research*

Through completing this review, it became clear that the literature around use of climate and weather information in agriculture has evolved over time. Early studies focused on the potential of forecasts and problems with farmers' awareness and ability to interpret available forecasts and information. A few articles emphasized the need to educate farmers or advisors to increase use of existing forecasts in their operations. Later studies highlight the importance of a more participatory approach, in which two-way communication is valued for developing and tailoring weather information/DSTs to users' needs. This parallels findings from other areas of research on the importance of user involvement in the ultimate usability of scientific information, such as that reported in Dilling and Lemos (2011). Participatory approaches could be expanded to additional regions beyond the southeastern United States and Australia to cover more agricultural decisions and issues (Carberry et al. 2002). We agree with Cabrera et al. (2008), Roncoli (2006), and others who emphasized the need for interdisciplinary research teams to tackle this topic: ''Participatory modeling for climate applications holds a great promise for future work but requires interdisciplinary teams to embrace the greater complexity among human, natural resource management, and climate systems'' (Cabrera et al. 2008, p. 406).

From a methodological standpoint, early research tended to rely more exclusively on survey methodology, and appears to be less rigorous in terms of sample sizes and generalizability than later research. Research from the early 2000s on has shifted toward using mixed methods approaches, combining both quantitative (such as surveys) and qualitative (such as interviews and focus groups) research methods. This is a positive development that likely signals more thoughtful application of social science to these weather/climate information issues, since surveys are not a ''one size fits all'' methodology to answer every research question (Prokopy 2011). Future research should continue to critically apply the most appropriate methods to explore new research questions about farmers' use and perceptions of weather and climate information and DSTs. For example, if researchers are interested in how broadly a particular DST has been used, a survey may be the best method, but if they want to know why a certain group of farmers are/are not using the DST, qualitative methods such as interviews would be more appropriate [for more on applying social science methods to DST development, see Prokopy et al. (2013b)].

This review revealed some weaknesses and gaps in this body of research. While there has been significant study of the southeastern United States, less research has explored farmers in other regions of the United States in terms of their perceptions and use of weather and climate DSTs. Similarly, little to no social science research has been conducted in Europe with farmers or agricultural advisors to explore their use of climate information and tools for decision making, particularly in response to global climate change. Since different regions and agricultural systems are subject to different climate projections and impacts, it is critical to understand the needs and behaviors of the diversity of U.S. and European farmers regarding weather and climate information and adaptation to climate change. A similar area requiring further study is how farmers operating in different types of agricultural systems in varied contexts may have different perceptions and uses of climate information or DSTs (Breuer et al. 2009; McNew et al. 1991). For example, large-scale corn and soybean farmers in the Midwest are likely to have different concerns and needs for weather and climate decision support information than organic vegetable producers in California. Further research should be conducted to understand which forecasts or tools different types of farmers are already using, when they need them, and for which decisions they are already using climate information (Hu et al. 2006) potentially as case studies exploring these issues with subgroups that are underserved or unconventional. Related areas requiring further study are the power and politics of weather and climate information and forecasts, in terms of who has access to the information and forecasts, and the role of power in who benefits most from these advancements. These topics have been explored more in developing countries (see Lemos et al. 2002; Broad and Agrawala 2000; Nelson and Finan 2009) but deserve to be considered in more industrialized contexts.

The focus in this literature on farmers more than advisors may be appropriate, but has left a gap. Although farmers are the ultimate decision makers in agriculture, advisors may be the ''primary'' users of climate information and tools as they can use this information and/or forecasts to enhance the advice they give to farmers. Farmers may not have the time, energy, interest, or capacity to convert weather forecasts and tools into usable information for decision making. Advisors have the potential to act as brokers of this type of information as they guide farmers toward decisions. Future studies should explore more types of agricultural advisors and their perspectives and uses for weather/climate DSTs.

Much of the existing literature examines farmers' perceptions and use of seasonal climate forecasts specifically, while less research has addressed more general weather or climate information and DSTs. To address this gap, future research should focus on other types of weather forecasts and information that may be more relevant to particular issues or contexts. For example, SCFs based on El Niño are more effective and relevant in some regions such as the southeastern United States, but broadening the scope of types of forecasts and information examined in research could identify better ways to address the needs of agricultural decision makers across the United States and other developed nations. Research conducted in additional agricultural contexts with new variables drawing from more models and forecasts would be valuable (Jochec et al. 2001; McNew et al. 1991).

This review highlighted how social science concepts and theories such as social capital, social networks, social norms, and the diffusion of innovations have guided researchers' understanding of perceptions, use, and barriers to broader use of climate information and DSTs in agriculture. These theories and others can help research in this area go further in the future, since research solidly grounded in social theory is somewhat sparse. Several authors—including Furman et al. (2011), Hu et al. (2006), Jagtap et al. (2002), and PytlikZillig et al. (2010)—saw a need to better understand the social relationships that influence farmer decision making as well as the role of trust in farmers' use of climate information. There is also a gap in the literature in terms of farmers' attitudes toward the usefulness of climate forecasts, how they form, and the role of past experiences on attitudes toward climate forecast (McCrea et al. 2005). Future studies could more explicitly use theoretical frameworks, such as theories of risk perception, the diffusion of innovations framework, or theory of planned behavior/reasoned action approach to guide research on these topics.

5. Conclusions

After examining this literature, we can draw a few conclusions about farmers' use of climate information, forecasts, and DSTs, as well as their perceptions of usefulness and limitations to broader use. Overall, it appears that there is room for improvement of weather and climate information and tools if developers want to achieve broader use in agriculture. Increasing forecast ''skill'' or reliability would help, but convincing farmers of the improved accuracy and trustworthiness of weather tools is crucial (Breuer et al. 2008; Carberry et al. 2002; Hu et al. 2006; Vining et al. 1984). Many articles contained recommendations for improving the use of weather information and tools in agriculture. Hansen (2002) emphasizes the need for ongoing support and engagement from the organizations that develop DSTs in order to sustain use by agricultural decision makers. Changnon (2004) suggests incorporating additional climate information into forecasts/tools, such as historical data, growing degree days, and comparisons between current year predictions and recent years with similar weather so farmers can link forecasts with past yields. The need to provide information that is useful, relevant, and context specific for a given agricultural sector was an important theme of this literature (Artikov et al. 2006; Breuer et al. 2008; Carberry et al. 2002; Carlson 1989; Changnon 2004; Crane et al. 2010; Furman et al. 2011; GAO 1979; Hansen 2002; Hu et al. 2006; McNew et al. 1991; Nelson et al. 2002; Prokopy et al. 2013a; PytlikZillig et al. 2010; Roncoli 2006; Weiss and Robb 1986). To increase farmers' use of information for better decisions, weather and climate DSTs should be developed with input from the end user and packaged to be more usable and relevant to specific agricultural contexts. Collaborative approaches that allow farmers and/or advisors to help design a tool are likely to be the most effective way to encourage use of information or DSTs. Other benefits of participatory DST development highlighted in this literature include ownership over the end product and improving users' trust in and understanding of weather forecasts (Power et al. 2007).

Another conclusion we can draw from this review is that thus far relatively little research has been conducted on advisors to farmers who have the potential to be valuable partners in interpreting and transferring climate and weather information to farmers. When they are trusted sources of advice and information, they may be an untapped resource in efforts to increase use of weather and climate information in agriculture (Breuer et al. 2010; Prokopy et al. 2013a). As climate change increases the stress on agriculture across the globe, there is certainly potential for additional social science research on agricultural decision makers' perceptions and use of weather and climate information to inform the development of improved information and DSTs.

Acknowledgments. This research is part of ''Useful to Usable (U2U): Transforming Climate Variability and Change Information for Cereal Crop Producers,'' and is supported by Agriculture and Food Research Initiative Competitive Grant 2011-68002-30220 from the USDA National Institute of Food and Agriculture and by the Purdue Summer Undergraduate Research Fellowship. Project website is http://www.AgClimate4U.org. The authors thank Rebecca Pritchard, undergraduate research assistant, for her help in locating and categorizing articles.

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