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Climate Services for Agricultural and Livestock Producers: What have we learned?

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ABSTRACT

Climate services are scientifically based products that enhance users' understanding on the impacts of climate on their decisions and actions. Decision Support Systems (DSSs) are programs that use models and other information to make site-specific recommendations for farm management-related activities. Climate variability is a source of production risk worldwide and is associated with other risks such as pest and disease incidence. Extreme climate events such as drought, intense precipitations, and pest or disease outbreak can also affect commodity prices and increase marketing risk. However, climate forecasts alone usually do not provide actionable information for improving decisions and policy. Climate forecasts are the basis for co-development of DSSs to support improved decisions at different scales to maximize profits and input use, and to minimize climate risks, and negative environmental externalities. Major advances in developing DSSs occurred through design, diffusion, and adoption made possible through continuous interaction among scientists, boundary organizations and end users in a participatory research and development process. This article describes the evolution of this process and addresses issues of co-development, participation, scale, and future research needs through a case study that highlights commonalities and differences between producer needs, perceptions, and adoption at two research sites (one in Florida, USA and the other in southeastern Paraguay).

Introduction

In the coming decades, the growth in global population will require a substantial increase of global food production. At the same time, a variable and changing climate, extreme meteorological events, and emerging threats from pests and diseases are likely to negatively impact yields. Climate services are decision aids derived from climate information that assist individuals and organizations in society to make improved ex-ante decision-making (WMO, 2019). Climate services requires appropriate and iterative engagement to produce timely advisories that end-users can comprehend and which can aid their decision-making and enable early action and preparedness. Climate services need to be provided to users in a seamless manner and, most of all, need to respond to user requirements. The World Meteorological Organization (WMO) has identified five societal sectors to concentrate global efforts on providing climate services. The sectors are public health, energy, water, agriculture, and extreme events (disasters).

In the coming decades, in order to achieve the Sustainable Development Goals set out by the United Nation (UN, 2015), agriculture will play a key role. Reducing or eliminating hunger, malnutrition, and poverty are important objectives at several scales. Concurrently, nations and producers must strive to meet the economic, social, and environmental sustainability of food, fiber, feed, and fuel production. Climate change may become an effective barrier to agriculture and livestock growth in many regions, especially in the global south, much of which is non-irrigated and therefore is dependent on the vagaries of precipitation.

This article will deal specifically with climate services for producers in the agricultural and livestock sector and discuss the past, present, and some likely future trends in climate services for agricultural producers. A comparative case study using data elicited from producers in two latitudinally analogous regions, North-Central Florida, USA, and Itapua Department, Paraguay, is used to illustrate producer needs, forecast and decision scales, forecast delivery preferences, the role of boundary organizations in translation and delivery of climate services, the linkage of climate information packages to farm management options for climate adaptation. Additionally, the paper addresses considerations on production systems` rigidity or flexibility, with regard to their resilience to the impact of extreme events. The article summarizes lessons learned to date on decision support tools and systems and early warning or alerts, and identifies knowns and unknowns or gaps in this field of applied research, with a special focus on Eastern Paraguay, that may be informative at the regional level.

Climate Change requires a Science Change

Humans have sought to mitigate climate risk since the dawn of agriculture. Among the most ancient forms of risk management are crop diversification and irrigation. Irrigation existed from the Fertile Crescent, to the Indus valley civilization, to China, Mexico, and ancient Peru, and was such a powerful tool in civilizational development as it allowed a smoothing of the production curve over good and bad rainfall years (Price,1994). Likewise, diversification, both in crops and in geographical location was prevalent, especially in sub-tropical and tropical settings. When one crop failed, another was usually available to provide food security. Since the mid-20th Century, and with greater intensity since the 1990s, however, many parts of the world have tended toward more specialized, less diverse cropping practices (Bradshaw et al., 2004). In modern times, crop insurance has come on the scene as another form of climate risk mitigation (Di Falco et al., 2014; Cabrera et al., 2007). However, to date, this instrument is most common in high-income, developed countries, and its use in the developing world is incipient, but growing at differential rates in different countries and regions. (FAO, 2019).

Climate variability causes production risk in agriculture. The major source of yield variability, perhaps over 80%, in agriculture is drought (FAO, 2017). Excesses in total precipitation and intense rain events are also damaging, especially to specialty crops. The impact these climate events have at different moments, on different crops, and in different parts of the world also affect global and local market prices.

In light of limited irrigation, diversification and crop insurance in Paraguay and Latin America in general, the use of climate information becomes crucial. Although it is widely regarded that most agricultural producers respond rapidly to changes in their environment and often adjust within the growing season (Crane et al., 2011), science must support adaptation actions that have a broader future outlook than those based solely on past and present experience. In other words, science must be connected with adaptation practice or action. To accomplish this, scientific input into the adaptation process must remain salient, credible and legitimate, which is a process achieved through trust-building through working with producers and boundary organizations (Meinke et al., 2009; Breuer et al., 2008; Cash et al., 2003).

The science of developing climate services as decision support or early warning systems aimed at producers has advanced in recent years. However, broad adoption and use for practical management adjustments has not occurred when forecasts are provided in raw form. For the useful to become useable (Prokopy, 2017) climate forecasts must be user-friendly and linked to feasible farm-level decisions that producers are willing to make, and to public policies that support such use (Fraisse et al., 2006; Breuer et al., 2009; Han et al., 2017).

The most widely used climate services for agriculture are climate-based DSSs that integrate climate information with crop and farm models to provide weather and probabilistic climate outlooks and other information to aid producers in their decision-making. One example of this is AgroClimate (Fraisse et al., 2006), developed in the

Southeastern United States to provide tools and outlooks, both to the Extension Service and end users (producers) for climate-based risk reduction decisions. The system provides a range of tools, including chill hours and growing degree day accumulation models, disease risk alert tools, and yield potential for alternative planting dates and climate scenarios. Because the US Southeast has a strong ENSO signal, several of the tools permit the selection of different ENSO phases when interacting with the system for decision support.

Recently, researchers developed several decision support suites using different levels of interaction with end users. Among these, we may cite Yield Prophet, which provides information for Australian farmers on impacts of climate on crop growth and yield, disease occurrence, and recommended management practices based on several crop simulation models (Hochman et al., 2009). A new yield tool for maize, wheat, and soybeans in based on DSSAT models with daily in-season updates, for Argentina—with a pilot phase in Paraguay—is already being used for more informed decisions by producers and policy makers (Gamarra, 2017). Finally, the Climate-Agriculture-Modeling and Decision Tool (CAMDT) displays DSSAT outputs as well as translated outputs for users. According to its developers, the system can support better-informed adaptation strategies by providing easily accessible scenarios of management adjustment practices, under expected seasonal climate scenarios (Han et al. 2017).

Climate science is one of the most integrative sciences. Although, much of the physics of the climate system and agronomic sciences were discovered in the past century, the crucial issue of decision-making only advanced toward the end of the 20th century and into the 21st century years. A systems approach at the farm scale must include not only the biophysical component, but also the social, economic, and political environment of the farm together with a ‘bottom up’ approach (Breuer et al., 2009). Connectivity and dialogue among key players is essential for achieving relevant and significant intervention. These approaches are not about science simply providing the answers for management to practitioners, but rather employing cooperative learning to develop solutions (Meinke et al. 2001, 2009).

Podesta et al (2013) posit that intractable, “wicked”, current and future environmental issues requires insights and methods from many disciplines. Furthermore, to reach social robustness in a context of uncertainty and multiple values and objectives, participation of relevant social actors is required (Podesta, 2013; Meinke et al., 2009). Meteorology and climatology provide us with insight into the climate system through statistical and dynamical modeling. They provide us with the weather and climate models that are a starting point to climate services. Agricultural or agronomic science, especially crop modeling, and whole-farm modeling, which in itself consists of joint research with agricultural economics and ecology, provide us with intuition on potential adaptations in agricultural systems. Finally, the socioeconomic sciences, and special areas such as anthropology, rural sociology; allied with cognitive psychology and the decision-making science branch of economics, provide us with insight into decision making by producers and policy makers at several scales.

Method of choice: continuous stakeholder interaction

Farmer participation and workshops serve to identify information needs as well as provide feedback on the decision support tools and technologies developed by research (Roncoli, 2006; Breuer 2008, 2009). Diversity and flexibility of approaches to climate forecasts, using a broad interdisciplinary approach, participatory approaches, should include some degree of interaction between farmers and scientists.

To develop Agroclimate, researchers used a co-production of knowledge and decision-making approach that involved intense and continuous iteration with potential end-users, including farmers, Extension professionals, and agricultural advisors. Researchers used interviews, focus groups and surveys, feedback at outreach events, and frequent informal interactions to develop both decision support tools and delivery mechanisms that met stakeholder needs (Breuer et al., 2008, 2009). Led by researchers at Purdue University, the Useful to Usable decision tools dashboard focused primarily on maize was developed to provide useful and usable climate information for the agricultural corn sector in the Midwestern United States, using a similar methodology (Angel et al., 2017; Prokopy et al., 2017).

Decision support tools are not intended to make decisions for farmers. These systems should support their abilities to explore different options and choose solutions (Meinke et al. 2001, 2009; Podestá et al., 2002). Of particular importance is the fact that by nature, most climate forecasts are probabilistic. One of the greatest challenges is the learning process for all stakeholders that making decisions based on probabilistic information entails.

At the policy level, stakeholders in governments, planners, communities, individuals, industry, and interest groups frequently disagree about the relevance and effectiveness of climate mitigation and adaptation strategies due to differences in culture and values. Thus, the use of participatory methods that incorporate many vulnerabilities and solutions is an effective approach for designing a DSS useful across several spatial and temporal scales and for many potential stakeholders (Rogers 2003;

Adger et al. 2013; Jacques et al., 2017).

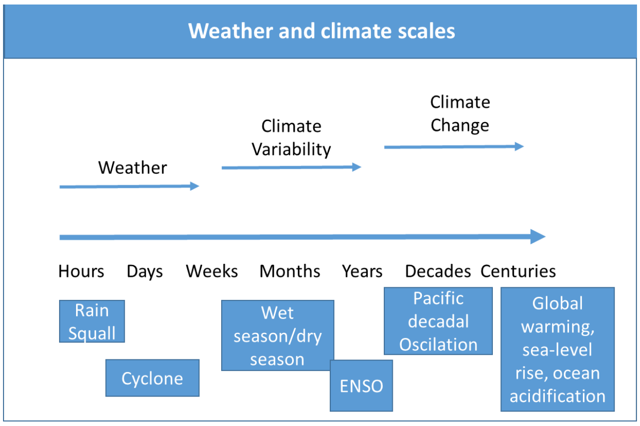
Direct participatory action research with farmers has helped establish credibility of models, simulation analyses, and DSSs. Software created for and with farmers, extension agents, and farm consultants should be user friendly, deliver quickly and easy results, have an understandable format, address site-specific conditions, and be in real or near-real time (Archer et al. 2002; Cabrera et al. 2008).

Issues of Scale

The issue of scale, both temporal and spatial is crucial to the development of useful and useable DSSs. Some systems, such as DSSAT, especially with its broadening into a global community through the AgMIP Project (Rosenzweig et al., 2014) are more amenable to global or regional food security applications and public policy formulation, under long term climate change. Others, such as AgroClimate (Fraisse et al., 2006) are more suited to farm or local level decision making for tactical or strategic planning for risk reduction on a short-term or seasonal time scale. Tactical decisions include daily or weekly operational decisions such as: when to plant, when to apply nitrogen in the field, when to spray fungicide, when it’s dry enough to harvest, when to cut grass for hay, and when to turn on aspersion for frost protection. Stategic decisions are longer term and include, for example, what crop and variety to plant this season, how much to invest in fertilizer before the season and what application system to use, crop insurance purchases, marketing decisions, and purchasing cattle feed or planting cool-season pastures before the winter season.

Not every type of climate service is useable to a producer. Many are at scale where only larger units, such as farmer organizations, cooperatives, or the State can push for or enact policies to mitigate damage or take advantage of positive outlooks. Some climate services, such as scenarios for 80-100 years into the future, are rightfully of little interest to the individual producer. These projections are aimed at action at the global scale and on a secular period.

Figure 1. Temporal scales of weather, climate variability, and climate change. Based on Australia Climate Change Science and Adaptation Planning Program.



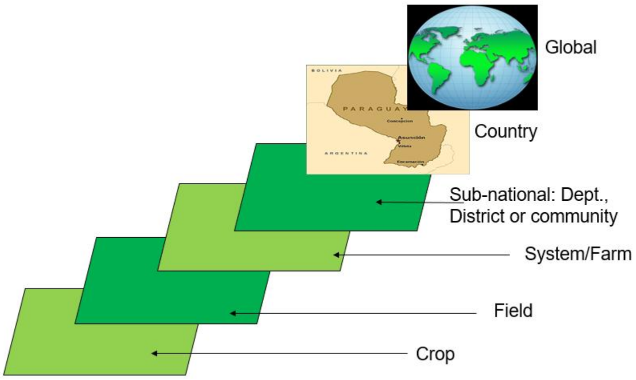
This may be seen as a means to adapt to longer-term climate change through enhancing resilience at the farm-level by providing useful and timely information for adjusting farm management in light of forecasts of common meteorological variables or even extreme events, which is how climate change impacts growers and is felt at the field or community level.

Researchers use decision making in light of possible extreme events based on their understanding of more frequent or extreme weather events as a proxy for how producers will make decisions related to long-term climate change making. They find that this assumption was used by scientist for many years and is patently inaccurate as the mental mechanisms used to make long-term, permanent climate change decisions is completely different from planning for extreme events. This fact is one of the most important findings on scale in agricultural and livestock decision making to have emerged in the recent literature.

Participatory research for Climate Services Participatory research comes from the context of farming systems research for international rural development. This research and extension sought to increase technology adoption by involving farmers in developing and testing innovations (Chambers 1994, 1995; Hildebrand 1981; Stringer et al., 2006).

Some of the main benefits posited for participatory research in climate services are: it may be the best way to understand stakeholder needs (rather than wants); it provides opportunities to network and discuss joint research activities; it is useful for input, feedback, dissemination, and co-development of DSS and tools. In addition, it provides a measure of accountability and transparency to all involved; may improve stakeholders’ “buy-in” and some measure of ownership of the project,

Figure 2. Spatial and Institutional Scales.



thus potentially increasing adoption; may enhance the legitimacy of the investigation in the eyes of stakeholders finally, may nurture equality by placing researchers and other stakeholders on a level playing field (Reed, 2008).

Simulation models and decision support tools can also facilitate learning by farmers as well as scientists by enabling them to explore different options and the potential risks and gains associated with them. This process is much richer than the traditional "loading dock" or "pipeline" approach to technology transfer (Roncoli, 2006; Crane et al., 2008, 2010; Bartels et al., 2013; Breuer et al., 2009; Roncoli 2006; Chambers 1994).

A large toolbox is available to participatory DSS action researchers. These include interviews, surveys, crowdsourcing, facilitation, role-playing games, rich pictures, cognitive mapping, causal loop diagrams, cultural consensus, decision tree analysis, fuzzy cognitive mapping, social network analysis, scenario building, analytical hierarchy processes, empirical modeling, Bayesian belief networks, system dynamics, agent-based modeling, cost-benefit analysis, and integrated modeling. The authors also provide a guide as to which methods to use given determined goals under different circumstances (Voinov et al., 2018; Breuer et al., 2009).

The most common methods are Sondeos (or Participatory Rural Appraisal), a semi-structured, multi-disciplinary team process that uses discussions rather than formal questionnaires to obtain information about agricultural practices. An important benefit to a conversational approach is that it elicits key issues that the researcher may not have anticipated, issues likely missed with a standard survey with a pre-established list of questions (Hildebrand, 1981; Cabrera et al., 1999; Breuer et al., 2008).

Semi-structured interviews use an interview guide. Focus groups are recruited to discuss a particular topic. Typically made up of six to twelve members, focus groups are relatively inexpensive. Focus groups do not replace, but rather complement surveys (Bernard, 2010).

Web-based surveys are a modern variant of the traditional large sample surveys (Cabrera et al., 2006; Breuer et al., 2010; Templeton et al., 2018). Researchers elicit detailed, quantitative data through this method. Workshops are brief, intensive courses for small groups that promote learning, discussion and feedback. Farmer association meetings are one to three day events held by an organized body of people who have an interest, activity, or purpose in common; in this case, agricultural production of a particular commodity. These sessions are useful for discussing climate forecasts, or to present decisions support tools to the general assembly.

On-line feedback is real-time information obtained from users of a DSS web site. The form should be voluntary and easy to fill out. Researcher incorporate comments, and questions into the DSS if deemed useful and appropriate (Barham et al., 2004). Finally, advisory panels of experts round out participation on an on-going and accountable basis (Fraisse et al., 2006; Breuer et al., 2009).

In related research at longer temporal scales, scenario-based stakeholder engagement brings together stakeholder analysis, climate change management scenarios, and deliberative techniques. This method explores the necessary trade-offs associated with long term environmental planning. An advantage of this method, along with "serious games" is that they take the complexities and challenges of climate change into account, and can be used in conjunction with existing approaches (Tompkins et al., 2008).

One study showed that the greatest quantity of feedback was obtained through Sondeos, interviews, and web surveys. The greatest quality of feedback came from web surveys, workshops, interviews and Sondeos. Dissemination of climate forecast technology and applications were greatest at farmer association meetings and lowest at workshops. All methods contributed to DSS co-development (Breuer et al., 2009).

The SECC Experience:
Participatory Development of AgroClimate

The Southeast Climate Consortium (SECC) was a Regional Integrated Science and Assessment Center funded by NOAA. In late 2004, the SECC released AgroClimate (Fraisse et al., 2006), a prototype DSS for climate risk reduction in agriculture. The process of participatory development of the website included regular surveys and workshops to assess producer and extension agent awareness of, attitudes toward, and interests (Breuer et al., 2008) in climate data, and to provide continuous feedback to the research and development team who were creating tools for the DSS. Based in part on concerns with the necessary differentiation of DSSs intended for use by scientists and those designed and aimed at directing behavioral change farmers, policy makers, or extension agents, the SECC adopted participation as an appropriate focus (Breuer et al., 2008; Roncoli et al., 2012; Crane et al., 2010).

The explicit aim of participatory research in developing AgroClimate was to learn from and support agricultural producers adaptation to seasonal climate variability. The idea was to translate raw climate forecasts into derived forecasts and finally to feasible management adjustment options, often suggested by producers based on their own experience and environments (Roncoli 2005; Crane et al., 2008, 2010; Breuer et al., 2008). These adjustments, fine tune or "tweak" rather than change management. Derivative processes and products using the same methodology led to tools for use by wildfire managers (Roncoli et al., 2012) and water managers (Bolson et al., 2012).

Climate information delivery requires some understanding of its probabilistic nature (Breuer et al., 2008). According to Hartmann et al. (2002) forecasters and their evaluations typically reflect forecaster, or scientist perspectives, rather than those of users. However, research shows that farmers' ability to interpret probability and integrate this information into decisions can improve over time (Suarez & Patt 2002; Hansen 2002). In addition Findlater et al. (2019b), found that farmers' decisions regarding weather information was profoundly different from those with respect to long-term climate change. Forecast information can have value only if people can change their actions in beneficial ways based on the content of the information (Letson et al., 2005). Surveys showed that DSSs could help guide decisions about what

crops and varieties to plant, where on the property a crop should be planted, and when to plant, fertilization rates, insurance purchases, input purchases, and input applications, and marketing decisions. Climate factors of importance in relation to these decisions include temperature, rainfall, humidity, and sunlight, chill unit accumulation and growing degree-days. Interviewees stressed the importance of extreme events such as storms, floods, droughts, frosts, freezes, and hail.

It is worth noting that many farmers remain skeptical about the validity and reliability of seasonal climate forecasts, especially regarding local variations. Diversity of agro-ecological conditions and farming systems directly influences the importance placed upon seasonal climate variability and decision-making by extension agents and farmers (Bartels et al., 2013). Producers insist that for a forecast to be used it must be at a level of sufficient resolution that it relate to their personal farm or county rather than for a region. Several producers identified within season distribution of rainfall as more important than seasonal total, which is particularly important in areas of sandy soils having low water retention capacity. Typically, mixed crop and livestock farmers avoid risk by managing for adverse climate years as was noted by Thornton et al. (2004).

Decisions regarding management practices depend on many factors, not just climate. Many farmers are "locked in" due to lack of flexibility in their farming systems. They express concern about the cost of changing management practices and insist that any recommendation should integrate the whole production system. If the potential benefits of responding to a climate forecast are relatively small per unit area, or if costs of implementing recommendations are high, then only farmers with plentiful resources on large farms might profitably use such recommendations. At the regional planning and policymaking levels, however, aggregate benefits are an important consideration in cost-benefit analysis of using or recommending climate-based decision support. Many growers state that influences on their decisions are highest from government regulations and market fluctuations. Other concerns include availability of labor, and free trade agreements.

Small and organic farmers are on average, less interested in variety or crop recommendations than were larger farmers because they tend to mix crops and varieties in order to diversify and minimize risk whereas larger farmers grew fewer crops and varieties in order to achieve economies of scale. Small and organic farmers reported an interest in getting recommendations for pest and disease management practices that depend on climate, and in detailed frost information (Furman et al., 2011, 2014).

In the southeastern United States context, Extension agents considered women and adolescents to be more likely to use the Internet. In the Southeast USA farmers, wives handle many of the logistical details involved in the operation of the farm, a crucial gender observation leading to the notion that DSSs might be targeted to this audience. Older farmers with less computer experience may not be comfortable using web-based technology. The issue of access of and skillful use of the Internet is even more crucial in developing country contexts.

Emerging recommendations from Participatory Climate DSS Research

Tailoring climate information to risk management problems is key methodological issue. Early and effective engagement with stakeholders is essential. Timely and effective implementation depends largely on institutional mapping (Breuer, 2008; Bartels et al., 2013; Hartmann, 2002).

Foundational work (Mjelde et al. 1988; Stern & Easterling, 1999; Letson et al., 2005) had posited that forecasts are useful and have value only if they permit ex ante actions, such as altered choice of crop species and cultivars and shifting planting dates. Interviewees often agree that forecasts are helpful only if they arrive well in advance, to support making decisions on when to plant, input purchase, or stocking rates. Many farmers express the idea that forecast lead-time holds greater importance than accuracy. Furthermore, site specificity or local conditions are necessary and positively affect the usefulness of forecasts (Templeton et al., 2018; Breuer et al., 2010, 2011).

A list of recommendations emerges from work with agriculture, livestock and forestry producers that other researchers may choose to heed in future work. Among these are, that researchers need to focus on integrated decisions; decision makers are interested in information on a continuum of time scales; early and continuous partnership with users is essential; shared learning and joint problem-solving is key; outreach and dialogue programs should be priority activities; building trust and credibility is a long-term endeavor; and continuous, interactive dialogue is essential. In addition, researchers need to stress probabilistic nature of forecasts; understand the decision calendar and decision-making process; be aware that co-production of knowledge improves adoption; acknowledge that experiences should be documented and shared; and that a problem-focused approach engages stakeholders better. Finally, understand place, context, history and decision-making process are key to success, useful and usable information responsive to different user needs is essential; and climate information system are more useful than simple event forecasting (Reed, 2008; Breuer et al., 2008, 2009).

Extension personnel and crop consultants (Prokopy, 2013) are “users,” who, in turn, become “producers” as they translate, repackage, or further analyze information for their clients. Members of boundary organizations are key to understanding farmer needs and adjustable management practices, and are as key as producers and scientists to include in participatory DSS development. A focus on developing DSSs that promote user-driven risk-management objectives where process and outcome are of equal weight can be achieved through participatory development and improvement. A collaborative, user-driven decision support system might even better withstand an incorrect forecast (Cash and Buizer, 2005). DSS use adds to systems resilience and is a crucial component to adaptation to climate variability and change in agricultural production.

Results and discussion

As a case study, we compared results from surveys with producers and technical personnel in Paraguay and Florida. We discuss results of exploratory and mid-project work at both sites. The Florida site led to a DSS still in place and widely used. The Paraguay case led to a DSS that was only available for a few years and then discontinued.

Producers and technical experts at both sites revealed widespread concern over seasonal and decadal changes in known climate patterns. One great expressed need was information on heat waves, which have been increasing in summer, and the extent of drought conditions, among others. We also explored institutional arrangements and found that boundary organizations, the Cooperative Extension Service in Florida, and Production cooperatives in Paraguay play a role as strong facilitators of climate technology adoption.

The impact of ENSO phenomenon affects interannual variability of weather in both regions (Cunha, 1998; O`Brien, 1999). The studies, conducted separately, interviewed a sample of convenience of 109 stakeholders in North-Central Florida and 112 in the Itapúa Department of Paraguay. Both sites present opportunities to improve climate forecast dissemination, communication; and interpretations; and to develop or adapt research tools, methods, and data products for translating climate forecasts into information required to support agricultural decision-making. Most of the similarities end here. Tables 1-3 show some of the major differences between biophysical and socioeconomic factors for both study sites.

Florida is vulnerable to ENSO effects during the spring and winter months, with an excess of over 30% of the normal seasonal total precipitation across much of the state during an El Niño. During La Niña years, the opposite effect occurs. Deficits of 10% to 30% can last from fall through winter and spring (Baigorria et al., 2007). Higher than normal winter rainfall in El Niño years can adversely affect yields of winter-harvested vegetables (Letson et al., 2001; Jagtap et al., 2002). ENSO effects on cattle ranching production in Florida are less studied. Rainfall deficit may be critical from March to May. In northern Florida, deficits are likely to be more severe in April, while this phenomenon affects South Florida more in March during La Niña years. In El Niño years, from January to March, rainfall deficit is generally less. Impacts on rainfall deficit are less consistent during summer (Mearns, 2004).

Paraguay is also vulnerable to ENSO, but as one major difference with Florida, the full impacts occur in the summer months, when the major crop, soybeans, grows. The South American Monsoon affects Paraguay’s precipitation. Several studies have demonstrated the teleconnections between ENSO activity in the tropical Pacific Ocean and anomalies in the seasonal precipitation patterns in subtropical southeastern South America. Positive precipitation anomalies related to the El Niño event and negative anomalies during La Niña events have been found along southern Brazil, Uruguay, the pampas region and northeastern Argentina (Ropelewski & Halpert, 1996; Diaz et al., 1998; Grimm et al., 1998, 2000; Montecinos et al., 2000; Berlato et al., 2005).

Fraisse et al. (2008) characterized the influence of ENSO events on soybean yields in eastern Paraguay and analyzed the relationship between ENSO and precipitation patterns during different soybean developmental stages. Positive and negative soybean yield residuals occurred both in Neutral and El Niño phases. In the case of La Niña phases, the residuals were always negative. Regarding precipitation levels during the different phases of crop development the study indicated that potential negative effects of La Niña

Table 1. Some characteristics may act as preconditions that facilitate adaptation of climate DSS info.

Florida	Paraguay
More diversified production systems	Monocrop, commodity-oriented
Farmers assisted by the public Cooperative Extension Services	Farmers organized into large cooperatives that provide in-house technical assistance
Many have irrigation (45%)	Little or no irrigation
Older farmers (mean = 56)	Younger farmers (mean = 39)
Less frequent meetings attended (avg. 9/year)	More frequent meetings attended (avg. 14/year)
Wide diversity of soil types	More homogeneous soils
Typically buy insurance	No insurance

phases on soybean production occur primarily during the vegetative phase of crop development, between planting and blooming. The relationships are given for soybeans, as they are the predominant crop in the study area, however, the relationships between ENSO and other crop yields are similar for other regular season crops. We looked for commonalities among the questions posed to both groups. We summarize the combined results in the results section below.

Boundary organizations are third parties, intermediary organizations, bridgers, brokers, and information intermediaries, that are in between technology developers and end users or stakeholders. They act in diffusion, in support of decision-making, in setting standards, and in technology evaluation (Howells, 2006; Miller, 2001; Mantel & Rosegger 1987). They also play the role of catalysts of change such as initiating change within science networks and more targeted end users (Callon, 1994, 1980). Boundary organizations that mediate between funding agencies and research universities are positioned between the operational and policy levels, or between scientific technology creation and adoption of the technology (Jacobs et al., 2005). The Florida Cooperative Extension & Service is one such organization. It serves a role between a research consortium—the Southeast Climate Consortium—and farmers in the State of Florida, U.S.A.

Case Study Results

Producers and technical experts coincided at both study sites on the following characteristics they consider vital to good climate information.

Lead time: well in advance of when planting, input purchase, or stocking decisions are made.

This timing of forecast availability may be more important than forecast accuracy.

Rainfall distribution and onset is more important than totals.

Table 2. Some biophysical characteristics that may contribute to DSS adoption.

Florida	Paraguay
Mosaic of mostly poor soils	Homogeneous highly fertile soil
Semi-modal precipitation	Abundant, well-distributed precipitation
ENSO effect in Winter	ENSO effects in Summer

Table 3. Some technical characteristics that may contribute to DSS adoption.

Florida	Paraguay
More diversified production systems	Commodity-oriented
Monocropped often for many years	Crop rotation the norm summer winter normal, but summer always soy
Horticulture and ornamental high technology	No. 1 proportionally no-till planting in world
Lower use of Internet 64%	Higher use of Internet 82%

Table 4. Boundary Organization characteristics that may contribute to DSS adoption.

Florida*	Paraguay
Number	Number
1993: 54	1996: 35
2007: 33	2010: 67
Percent of farmers members	Percent of farmers members
1993: 2.28%	1996: 45%**
2007: 1.11%	2008: 67% (in our study area =100%)

Site specificity is necessary and positively affects the usefulness of forecasts.

Link to management adjustment options.

Summary of principal findings from early surveys.

Interviewees at both study sites coincided that climate services are important. However, many mentioned that government regulations and market fluctuations are as critical to farmers as climate information, but any information on climate is useful. Farmers expressed medium confidence in crop models and climate models. At both sites, farmers felt systems not flexible enough to allow many management adaptations.

At both sites, farmers and technical experts thought that particular farming systems and local contexts should be taken into account for improved forecasts. Ideally, they would like forecasts at the farm or municipal level. Farmers in Florida expressed that they would require 85% accuracy to make management adjustments whereas those in Paraguay identified 75% accuracy as sufficient. Both groups interviewed mentioned cattle, forestry, and some row crops as having greater potential for adaptation.

Management strategies include cropping patterns, pest and irrigation management, herd size adjustments, pasture management and hay making decisions, and wildfire risk management.

Within the identified sectors, ranchers were interested in better climate forecasts in order to prepare and adjust winter feeding. Paraguayan farmers were more interested in planning supplement purchases whereas Florida ranchers were interested in information to help them decide on planting cool season grasses such as ryegrass. It should be noted that older ranchers rely on experiential knowledge. More commercial, technical-minded ranchers welcomed climate forecasts in both study areas. Producers at both sites mentioned Purchasing or selling cattle before a very wet or dry season as useful.

Regarding forecast format, farmers asked that specific information be displayed quickly and up-front. Farmers want concise information; extension agents want in-depth information or links to it. Dates or timelines needed. Farmers at both sites regarded the inclusion of management guidelines as useful, but also wanted historical information for reference and market information. Producers preferred simpler information to complex scientific graphs that are time-consuming and difficult to interpret. Additionally, farmers and technical experts at both sites mentioned that other persons or institutions who are not farmers might benefit from climate forecasts, such as insurance companies, traders, government, and competitors.

Needs, feasibility, and willingness to adjust

Figures 4 and 5 shows a shared concept among interviewees at both sites. Producers began with long wish lists as to the types of management they would adjust if provided the right climate information. Upon further questioning, we found that adjustable management practices would not only have to be economically feasible, but farmers needed to be actively willing to use them.

In the end, interviewees at both sites identified only a small sub-set of the original wish list of management adjustments they were actually willing to do. These were crop selection, area to each crop, variety, cultivar, or event, planting date, and fertilization timing and rates.

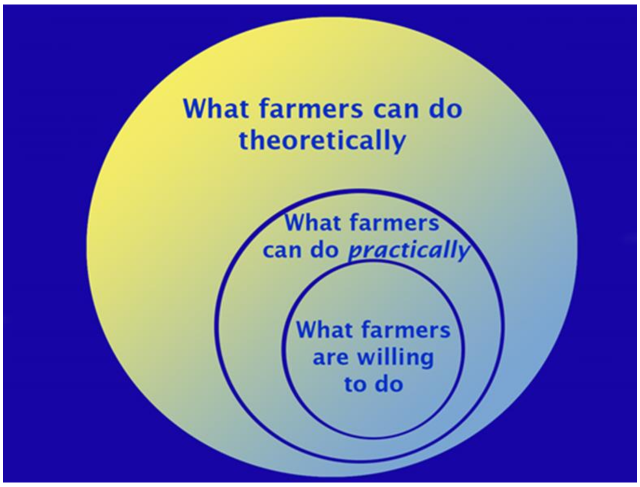
If interviewees at both research sites agreed on many major issues, why was the DSS more long lasting than the one developed in Paraguay? It is likely that the issues that led to this result were not related to the well-tested methodology adopted at both sites. However, it must be stressed that continuous stakeholder interaction took place throughout AgroClimate (United States) development, whereas, in the Paraguay case, this method was used initially, then abandoned for a more purely biophysical and computional approach. Institutional, funding, data, and other non-scientific issues produced longer lasting product adoption and use in the Florida than Paraguay. If the barriers mentioned are modified in the future, DSS adoption and use in Paraguay is highly likely to occur. At a minimum, the finding that many major decisions hold a strong similarity at both case study sites, in spite of holding validity for only the two sites, holds promise for better understanding the role of climate services in better farmer decision making, even in different systems, thousands of miles apart, and in different cultures.

What we know much about

Science learned much about climate services, such as decision support tools and systems for agricultural, livestock and forest producers. Among these findings, we know that climate forecasts at almost all scales are getting better. We can "translate" these forecasts according to local context for greater adoption, usability, and usefulness. We

Figure 4. The sieve of adaptable management practices.

Figure 5. Concentric circles of theoretical, practical, and willing to adopt management practices.



can offer management options developed in conjunction with boundary and end users for more widespread adoption. We can work with boundary organizations as intermediary users to reach end users. We can deliver DSS tools for different crops at different decision scales of via a wide variety of media and mechanisms, the internet and cell phones being the vehicles of choice at present.

What we know little about to date

Conversely, a dearth of knowledge continues to exist on several issues related to climate services and DSSs. little is still know about how each type of farming system functions as an integrated unit with particular goals. The complexity of farming decision-making (many factors, high complexity) continues to vex researchers who in many cases see responses to DSS tools as simple discrete yes/no responses. Many sources of rigidity exist. Among them are financial, markets, machinery, culture, institutional, political, legal, and others. Little is still known about what opportunities might exist to increase flexibility such as new varieties and crops, forest options, and how to incorporate them into semi-fixed systems. Finally the existence and economic realities of adopting new income sources such as environmental certificates, tourism, energy, are little developed.

Reasons for climate services for producers

Many reasons exist for farmers to adopt climate services in the form of DSSs. Among them are risk reductions, optimization of input use, and implementation of best management practices, to add resilience to their farming systems, and others yet to be investigated. Among the most pressing issues in light of increasing climate variability and change is that of increased resilience. All stakeholders must focus on methods for systems to embrace disturbance while maintaining long-term structural integrity. Human agency should provide an advantage on this issue as we have the capacity to add human to ecological resilience by incorporating learning. Integrated agroforestry and silvopastoral systems currently being researched by EMBRAPA are an excellent example of this type of research and applications.

Future Research

Future research into DSSs for climate services to producers should include realistic diversification schemes and the identification of many more insertion points for climate information to support risk management and optimization of input use. A much deeper understanding of producer decision making (need for social and decision sciences) is required along with knowledge of decision drivers at different scales (Findlater et al., 2019a,b). Large research teams are needed because much is known about the biological/biophysical, technical, infrastructural, and economic aspects of resilience. These aspects are quantifiable and environmental thresholds can be determined by looking at systems from "the outside". Social scientists are necessary members of multidisciplinary teams because the social realm, policy, human values, ethics, education and knowledge, attitudes toward risk, culture, community organization and social capital, and complex decision making are less understood (Adger et al., 2009; Findlater et al., 2019a).

Basic simple rules that many farmers follow must be understood and documented so that mistakes are not repeated in DSS development. One of the most common of these is avoiding all discussion of economics on DSS sites. Cost is a major concern in changing management practices for all farmers. They need to know how each adjustment suggest by DSS tools will affect their entire production systems. Studies are needed into how to remove rigidity from production systems for producers. Many farmers are "locked in" due to lack of flexibility in their farming systems.

An example of some of the items listed above comes from soybean and maize production in Eastern Paraguay. Farmers need seasonal-long-lead precipitation forecasts and rain onset estimations. The issue is crucial because a major objective for producers currently is to plant an early soybean crop in September in order to get a maize crop into the ground after harvest in the following January or February. DSS can help create a better fit for first crop soybeans and second crop or "zafriña maize". Without good climate forecast tools, maize planting is often delayed leading to reduced yields.

Future research on the decision making side must include an issue alluded to several times in this article, that is, that responses and decision making in light of extreme weather events is a bad proxy for the same processes with regard to long term, permanent weather changes. Social scientists must join biophysical scientists in interdisciplinary teams to tackle these type of seemingly intractable challenges of scale.

When Academia is absent, the void is often filled by private companies. Currently, large tech firms, with eyes set on AgTech or Smart Farming are using big data and advanced algorithms aimed at private consultants. These firms can often provide yield estimates weeks or months ahead of academic products by using their power in real-time imagery and big data analytics. If funds are not available and research is not directed toward providing useable climate services at all scales, academia may lose its position as the credible source of such information. The privatization of data useful to all farmers is an issue to be explored and reflected upon.

Finally, what producers want may be what producer's need, climate services that make their lives easier. DSSs delivered via cell phone, with simple, user-friendly forecasts coupled with management adjustments that producers are willing to implement are the here and now. Climate services that provide a suite of information that help farmers bolster their resilience in light of climate variability and flexibility are the "holy grail". These are within reach and we must continue to pursue their development as indispensable aids to sustainable development pathways.

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Serviços climáticos para produtores agrícolas e pecuários: O que aprendemos?

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RESUMO

Os serviços climáticos são produtos de base científica que aprimoram a compreensão dos usuários sobre os impactos do clima em suas decisões e ações. Os sistemas de suporte à tomada de decisão (DSSs) são programas que usam modelos e outras informações para fazer recomendações específicas por local no tocante a atividades relacionadas ao gerenciamento de fazendas. A variabilidade climática é uma fonte de risco de produção em todo o mundo e está associada a outros riscos, como incidência de pragas e doenças. Eventos climáticos extremos como seca, precipitações intensas e surtos de pragas ou doenças também podem afetar os preços das commodities agrícolas e aumentar o risco de comercialização. Entretanto, as previsões climáticas sozinhas geralmente não fornecem informações acionáveis para melhorar as decisões e as políticas do setor. As previsões climáticas são a base do co-desenvolvimento de DSSs para apoiar melhores decisões em diferentes escalas para maximizar lucros e uso de insumos e minimizar riscos climáticos e externalidades ambientais negativas. Os principais avanços no desenvolvimento de DSSs ocorreram através do delineamento, difusão e adoção desses ssitemas, por intermédio da interação contínua entre cientistas, organizações proximas do setor e usuários finais em um processo participativo de pesquisa e desenvolvimento. Este artigo descreve a evolução desse processo e trata de co-desenvolvimento, participação, escala e necessidades futuras de pesquisa por meio de um estudo de caso que destaca pontos em comum e diferenças entre as necessidades, percepções e adoção do produtor em dois locais de pesquisa (um nos Estados Unidos da América e outro no Paraguai).

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