Background paper for workshop "Insights and Tools for Adaptation: Learning from Climate Variability"
Organized by NOAA/OGP, Washington, DC, 18-21 November 2003

INTERANNUAL CLIMATE VARIABILITY AND AGRICULTURE IN ARGENTINA: WHAT DID WE LEARN?

Guillermo P. Podestá, Kenny Broad and David Letson
University of Miami, Rosenstiel School of Marine and Atmospheric Science

Elke Weber
Center for the Decision Sciences, Columbia University

Jim W. Hansen
International Research Institute for Climate Prediction

Emilio Satorre,
Asociación Argentina de Consorcios Regionales de Experimentación Agrícola

Hilda Herzer
CENTRO de Estudios Sociales y Ambientales, Argentina

Balaji Rajagopalan
University of Colorado

Angel Menéndez
Facultad de Ingeniería, Universidad de Buenos Aires, Argentina

The emerging ability to forecast regional climate based on the El Niño Southern Oscillation (ENSO) phenomenon (Mason et al., 1999; Goddard et al., 2001) creates an exciting opportunity to learn how important and prevalent climate-sensitive systems such as agriculture may respond. Nevertheless, several empirical studies have identified theoretical and practical obstacles to the use of climate information and forecasts (Pulwarty and Redmond, 1997; Mjelde, 1998; Finan, 1998; Stern and Easterling, 1999; Roncoli et al., 2001; Broad and Agrawala, 2000; Broad et al., 2002; Lemos et al, 2002; Patt and Gwata, 2002). The obstacles are diverse, ranging from limitations inherent to the climate system's complexities (forecasts have coarse spatial and temporal resolution, not all relevant variables can be predicted, the skill of forecasts is not well characterized or understood, contradictory predictions may coexist), to procedural, institutional, and cognitive difficulties in receiving or understanding the information, or in the ability and willingness of decision-makers to modify their actions. For these reasons, we submit that benefits will not be derived automatically from the mere availability of seasonal climate forecasts. A deliberate effort is required to design and implement effective ways of using climate information in service of society.

This background paper aims to distill some lessons learned and insights gained during a multi-year series of projects sponsored by NOAA-OGP and the US National Science

Foundation to understand the use of climate information at seasonal to interannual scales to enhance decision-making in agricultural production systems in the Pampas of Argentina, one of the major agricultural areas in the world (Hall et al., 1992). As the main goal of this document is to promote discussion, we have not structured it as a recapitulation of our projects' tasks and results. Instead, we follow a helpful template by Sarewitz et al. (2003), submitting five general assertions on the use of seasonal climate information and forecasts to stimulate the exchange of ideas. We do, however, illustrate and support each assertion with examples from our work.

> ***Assertion 1.*** *The existence of predictable climate variability and impacts is necessary but not sufficient to achieve effective use of seasonal forecasts.*

If there is no predictable interannual climate signal and associated impacts on crop yields or economic returns for a given region, it is unlikely that agricultural stakeholders would benefit from climate forecasts. Establishing the existence of such predictable signals is a necessary first step. In the Argentine Pampas we confirmed an ENSO signal on precipitation (most apparent during October-November) and yields of summer crops (maize, soybeans, sorghum). Nevertheless, in addition to the predictability requirement, other conditions must be met before seasonal climate forecasts can result in improved outcomes (Lamb, 1981; Sonka, 1987; Everingham et al., 2002; Hansen, 2002; Meinke and Stone, in press).

First, climate information has to be relevant to and compatible with production decisions in the target system. In part, this depends on the existence of entry points for climate information and forecasts into the decision-making process (Jones et al., 1999). To explore this issue, we built a "decision map" of a maize production system in the Pampas and refined it during workshops with stakeholders. The map listed the main climate-related decisions involved in maize production, their timing (some decisions were revisited several times), and the climatic factors affecting each decision.

Second, alternative options must exist for a decision. Examples of alternative actions include land allocation among various farm enterprises (Messina et al., 1999) or the specific management of a crop (Meinke and Stone, 1997; Jones et al., 2000). The alternative actions should show an interaction with climate: that is, produce different outcomes under different climate conditions. Our decision map also included a real-world range of options for each decision, appropriate for the different climatic scenarios considered (e.g., a rainier than usual spring). Argentine agriculture has undergone substantial changes such as increased use of fertilizers and agrochemicals, genetically modified varieties (especially for soybeans), and no-tillage planting (Satorre, 2001). Intensive use of modern production technology gives farmers a broad spectrum of options to tailor management to an expected climate scenario. Of course, the existence of viable options needs to be explored for other production systems (e.g., smallholder or subsistence agriculture).

Third, decision-makers should be able to evaluate the outcomes of alternative actions. Crop models and simulation approaches provide a way to explore the consequences of a broad range of decisions (Hammer, 2000; Meinke et al., 2001). We completed a risk assessment effort that quantified the distribution of outcomes (yields and economic returns) for *current* maize production systems in the presence of ENSO-related climate variability (Ferreyra et al. 2001). That is, no management response to forecasts was considered. In contrast, a risk management study (Letson et al., submitted) explored viable changes in agricultural management under various predicted climate scenarios. Optimized outcomes with and without climate information were used to derive frequency distributions of the value of climate information that reflected variability both in climate conditions within a predicted ENSO phase and in commodity prices, two major sources of risk to production and income.

Fourth, the forecasts must have useful (or at least, well-characterized) performance and appropriate lead time and geographical and temporal resolutions. Unfortunately, the limited "track record" of seasonal forecasts may have discouraged farmers in the Pampas from use. There have been various characterizations of the skill of seasonal forecasts, both experimental and operational (Barnston et al., 1999; Wilks, 2000; Wilks and Godfrey, 2002; Berri et al., submitted). Unfortunately, these assessments often reflected the perspectives of climate researchers and forecasters, not users (Hartmann et al., 2002). Forecast performance must be measured and communicated in ways that are meaningful to potential users.

Finally, decision makers must be willing and able to modify their actions in response to climate information. This depends not only on the individual decision-maker's willingness to adopt climate-adaptive management in an already complicated decision environment, but also on the economic, institutional, and cultural context in which farmers make decisions (Eakin, 2000).

> ***Assertion 2.*** *There is a need to develop procedures to convert raw climate information and forecasts into likely outcomes of alternative decisions in climate-sensitive sectors of society.*

Climate forecasts must fit the decision processes in climate-sensitive sectors of society. Information on the likely outcomes of alternative decisions in agricultural systems is more relevant than a seasonal forecast on its own (Hammer et al. 2001). For example, a farmer probably is more interested in receiving likely distributions of crop yields or economic profits, rather than a precipitation forecast. Outcomes in agriculture can be estimated through process models (crop growth models) that frequently require daily weather as input. Analog historical data can be used, but records are probably short. Process models could be driven with output from high-resolution climate models. Unfortunately, these models still do not produce daily values with a realistic structure, whereas crop growth is very sensitive to the arrangement of daily weather.

There is a need to develop procedures to translate seasonal or monthly climate forecasts into multiple equally-likely, realistic daily weather sequences consistent with the historical record and forecasted conditions. We are developing approaches that combine (a) resampling of historical data or, possibly, model ensembles (to generate monthly/quarterly distributions of climate variables consistent with seasonal forecasts) and (b) stochastic weather generators (to produce multiple ensembles of synthetic daily weather series with statistical characteristics similar to those of historical data). The synthetic daily weather sequences can drive crop simulations or other process models.

We implemented a weather generator with parameters estimated separately for warm (Niño) and cold (Niña) ENSO events and neutral years that successfully captured differences between phases in the number and persistence of wet days, and in daily rainfall amounts (Grondona et al., 2000). Nonparametric weather generators provide an attractive alternative to traditional parametric approaches. We are currently experimenting with a nonparametric generator based on the K-nearest neighbors approach (Rajagopalan & Lall, 1999; Yates et al., 2003). This approach allows flexible generation of synthetic weather ensembles that can be conditioned on ENSO phase, tercile-based forecasts, or the full probability distribution forecasted for a climate variable. The tools described also can be applied to the investigation of lower-frequency climate variability. For example, the nearest-neighbor weather generator can be used to replicate an observed trend (e.g., a multi-decadal enhancement of precipitation in the Argentine Pampas that caused significant changes in land use), or a hypothetical trajectory of climate (e.g., resulting from CO_2 increase).

> ***Assertion 3.*** *Efforts to foster effective use of climate information and forecasts must be grounded in a firm understanding of the goals, objectives, and constraints of decision-makers in the target system.*

The goals and objectives of farmers' decisions (i.e., their objective functions, in decision theoretical terms) influence how climate information (both historical data and forecasts) is used. In turn, this has implications for how climate information should be presented and communicated, i.e., the design of climate forecasts and tutorials on climate information use. Decisions on the current contents and formats of climate forecasts make implicit assumptions about what farmers are trying to achieve and how such information will be used. *It would be useful to make these assumptions explicit and put them to test.*

Different types of non-normative decision goals can be pursued by farmers. For example, our work with farmers in the Pampas indicates that minimization of decision regret is a goal frequently observed, even if it results in lower material profitability. Farmers are particularly reluctant to act on probabilistic forecasts of climate conditions that may not materialize. The anticipation of looking "foolish" (in their own eyes or those of others), or of being questioned about their decisions (by a spouse, neighbor, or technical advisor) makes many farmers reluctant to act on forecasts, even if the expected value of such action can be shown to be positive. Another example of a non-normative decision objective is aiming for satisfactory target levels of returns, rather than profit maximization, reflecting the desire for cognitive simplification of decision tasks.

Deviations from normative decision goals have important implications for the ways in which climate information ought to be communicated. The probabilistic nature of climate forecasts needs emphasis and explanation for all users, as probabilistic thinking is a relatively recent evolutionary accomplishment (Hacking, 1975) and not something that comes naturally to even highly trained professionals (Eddy, 1982). Nevertheless, the expectation of a deterministic forecast that will turn out to be either "correct" or "false" is especially damaging in situations where the decision maker will experience post-decisional regret after believing that s/he acted on a "false" forecast. Better understanding of the outcome variables that matter to farmers also will provide guidelines on whether and how best to "translate" climate forecasts. If, for example, crop yields or the costs of production input get particular attention, it makes sense to "translate" a climate forecast into the agronomic yield, income, and/or cost implications that it holds (see Assertion 2).

Decision makers in numerous domains have been shown to have poor insight into their own decision processes and goals and objectives. This offers opportunities for interventions to help farmers to enhance their decisions. When made aware of the objective function and goals implicit in their past decisions, decision-makers tend to react in one of two ways. Some are surprised by identified objectives and the associated cues or information they are using in their decisions. Further, once aware of these objectives and cues, these decision makers may wish they were not using them: examples may include the unconscious gender discrimination in hiring decisions, or possibly crop yield maximization rather than profit maximization in farm production decisions. Other decision-makers may concur with identified goals, objectives, and their associated information cues once made apparent to them, but refuse to give up on them (e.g., the anticipation of post-decision regret), even if they violate normative models. Identification of accepted objective functions and decision goals would guide future model of decision-making and use of climate information. Rejected goals and objectives will help design decision aids and decision tutorials that will allow farmers to change their habitual decision processes.

> ***Assertion 4.*** *Existing stakeholders' networks and organizations may provide effective ways to disseminate and assess climate information and forecasts.*

At the root of most barriers or impediments to the use of seasonal climate predictions lies a fundamental misfit between the predictive capabilities and communication abilities of producers of climate information, and the expectations, needs and beliefs of potential users of predictions. To overcome this misfit, the informational message must be matched to the characteristics and situation of the target group (Stern and Easterling, 1999). Orlove and Tosteson (1999) stress that climate forecasts must be well matched to the problem frame, decision-making processes, and capacity for adaptive response of the users. However, the fit between forecasts and needs develops from the interaction over time of forecast producers and users, in which users learn to expand their options in response to newly available information, and forecasters adapt their products to the evolving capacity of users (Patt, 2000).

Interactions between producers and users of climate information and forecasts have been a part (often small) of various pilot projects on climate variability in southeastern South America (see, for example, Meinke et al., 2001; Podestá et al., 2002). However, these interactions are difficult to sustain beyond the lifetime of pilot projects in the absence of specific structures or organizations to support such interactions. Building institutions and linkages that currently do not exist is financially and politically costly, with benefits to be reaped sometime in the future. One solution, at least partial, is to build on, and enhance the capacities of existing institutions and networks (Cash, 2000).

Enhancing both the "climate literacy" and the ability of decision-makers to use climate information can be accomplished effectively through existing organizations that perform information translation and brokerage functions, or "boundary organizations" (Moser, 1999; Guston et al., 2000). Relevant examples of boundary organizations in the agricultural sector include governmental extension systems, or farmers' and trade associations. Boundary organizations offer multiple advantages for the dissemination and assessment of climate information and forecasts. They can connect information providers and users, and serve as mediators in situations where there is little trust and credibility (Moser, 1999; Guston et al., 2000; Agrawala et al., 2001). Most importantly, boundary organizations provide a useful alternative to the linear "pipeline" model of transfer and use of scientific knowledge that has been fairly prevalent among many forecast producers (who frequently use the analogy of putting climate products "on the loading dock" for users to pick up and use at their own risk). Boundary organizations, in contrast, facilitate the multi-directional flow of information (i.e., needs, output format, results, etc.) between science and decision-makers (Cash and Moser, 2000). Unfortunately, in most cases, boundary organizations lack the expertise and resources to take on the additional task of disseminating climate information, and their capabilities need to be enhanced.

> ***Assertion 5****. Research, teaching, and outreach on the environmental and societal implications of climate variability and change require a broad spectrum of talents and participants. Yet, our understanding of factors leading to the development and sustained operation of successful interdisciplinary research and outreach teams still is quite limited.*

It is generally accepted among researchers and science policy makers that the assessment of complex environmental issues, including climate variability and change, will require communities of investigators able to work in diverse teams and across disciplinary boundaries. A good example is the list of authors in this paper: it includes agronomists, anthropologists, climatologists, economists, engineers, psychologists and sociologists. However, systematic analyses of the challenges of multidisciplinary collaboration and stakeholder involvement in integrated science projects still are needed. Few formal studies have been conducted to explore the paradigms, incentives, and institutions that may nurture the development and sustained functioning of interdisciplinary research groups. These groups should involve diverse specialists willing to learn enough about a range of relevant disciplinary methods to combine such knowledge into an original synthesis that helps to raise understanding of system phenomena or to solve a real problem (Schneider, 1995).

Our previous work in the Pampas yielded many interesting (sometimes hard!) lessons about how to achieve interdisciplinary cooperation and about the optimal level of creative tension resulting from disciplinary heterogeneity (while avoiding its frustrations). Yet, we believe we still need to understand many issues regarding effective interdisciplinary research. Some topics that need to be addressed include how to handle differences in disciplinary language, reliance on qualitative vs. quantitative methods, and understanding of common goals. Other issues seem minor, but affect the motivation of participants, such as conflicting incentives (e.g., academic publication vs. development of stakeholder-oriented materials), academic or grant evaluations by mostly disciplinary peer groups, or the existence and reputation of publishing venues for integrated science. Finally, we need to understand better how to conduct outreach and communication of interdisciplinary scientific knowledge to take maximum advantage of the participation of diverse stakeholder groups and institutions (government agencies, NGOs, etc.).

Many important topics remained to be addressed in this necessarily brief review, such as the need for a properly conducted assessment of uncertainty as it propagates throughout various linked models, and the possible effect on final results or policy implications. Nevertheless, we hope the topics that were addressed will generate interesting discussions and fruitful exchanges of ideas.

ACKNOWLEDGMENTS

We gratefully acknowledge support from the Climate and Societal Interactions Program of NOAA's Office of Global Programs and the US National Science Foundation (Methods and Models for Integrated Assessment and Biocomplexity in the Environment initiatives). Some of the authors also have benefited from participation in NOAA-OGP's Regional Integrated Sciences and Assessment program, through support for the Southeast Climate Consortium (University of Miami, University of Florida, The Florida State University, and the University of Georgia).

REFERENCES

Agrawala, S., K. Broad, and D.H. Guston. 2001. Integrating climate forecasts and societal decision making: Challenges to an emergent boundary organization. Science, Technology, & Human Values 26: 454-477.

Barnston, A.G., M.H. Glantz, and Y. He. 1999. Predictive skill of statistical and dynamical models in SST forecasts during the 97-98 El Niño episode and the 1998 La Niña onset. Bulletin of the American Meteorological Society 80: 217-243.

Berri, G.J., P.L. Antico, and L. M. Goddard. Evaluation of the Climate Outlook Forums Seasonal Precipitation Forecasts of Southeast South America during 1998-2002. Submitted to *International Journal of Climatology.*

Broad, K. and S. Agrawala. 2000. The Ethiopia food crisis - Uses and limits of climate forecasts. Science 289: 1693-1694.

Broad, K., A.S.P. Pfaff, and M.H. Glantz. 2002. Effective and equitable dissemination of seasonal-to-interannual climate forecasts: policy implications from the Peruvian fishery during El Niño 1997-98. Climatic Change 54: 415-438.

Cash, D.W. 2000. Distributed assessment systems: an emerging paradigm of research, assessment and decision-making for environmental change. Global Environmental Change 10: 241-244.

Cash, D.W. and S.C. Moser. 2000. Linking global and local scales: designing dynamic assessment and management processes. Global Environmental Change 10: 109-120.

Eddy, D.M. 1982. Probabilistic reasoning in medicine: Problems and opportunities. In: D. Kahneman, P. Slovic, and A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases,* pp. 249-267. Cambridge Univ Press.

Everingham, Y.L., R.C. Muchow, R.C. Stone, N.J. Inman–Bamber, A. Singels, and C.N. Bezuidenhout. 2002. Enhanced risk management and decision – making capability across the sugarcane industry value chain based on seasonal climate forecast. Agricultural Systems 74: 459 – 477.

Ferreyra, R.A., G.P. Podestá, C.D. Messina, D. Letson, J. Dardanelli, E. Guevara, and S. Meira. 2001. A linked-modeling framework to estimate maize production risk associated with ENSO-related climate variability in Argentina. Agricultural and Forest Meteorology 107: 177-192.

Finan, T.J. 1998. Of bird nests, donkey balls, and El Niño: the psychology of drought in northeast Brazil. American Anthropological Association Annual Meeting, Philadelphia.

Goddard, L., S.J Mason, S.E. Zebiak, C.F. Ropelewski, R. Basher, and M.A. Cane. 2001. Current Approaches to Seasonal to Interannual Climate Predictions. International Journal of Climatology 21: 1111-1152.

Grondona, M.O., G.P. Podestá, M. Bidegain, M. Marino, and H. Hordij. 2000. A stochastic precipitation generator conditioned on ENSO phase: A case study in southeastern South America. Journal of Climate 13: 2973-2986.

Guston, D.H., W. Clark, T. Keating, D. Cash, S. Moser, C. Miller, and C. Powers. 2000. Report on the Workshop on Boundary Organizations in Environmental Policy and Science, 9-10 December 1999, Bloustein School of Planning and Public Policy, Rutgers University, New Brunswick, NJ. Belfer Center for Science and International Affairs Discussion Paper 2000-32. Available at http://environment.harvard.edu/gea.

Hacking, I. 1975. *The emergence of probability*. New York, Cambridge Univ Press.

Hall, C.M. Rebella, C.M. Ghersa, and J.Ph. Culot. 1992. Field-crop systems of the Pampas. In: C.J. Pearson (Ed.), *Ecosystems of the World. Field crop ecosystems.* Elsevier, pp 413-449.

Hammer, G. L. 2000. A general approach to applying seasonal climate forecast. In: Hammer, G. L., Nicholls, N., Mitchell, C. (Eds.), *Applications of Seasonal Climate forecast in Agricultural and Natural Ecosystems. The Australian experience.* Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 51 – 65.

Hammer, G.L., J.W. Hansen, J.G. Phillips, J.W. Mjelde, H. Hill, A. Love, and A. Potgieter. 2001. Advances in application of climate prediction in agriculture. Agricultural Systems. 70: 515-553.

Hansen, J. W. 2002. Realizing the potential benefits of the climate prediction to agriculture: issues, approaches, challenges. Agricultural Systems 74: 309 – 330.

Hartmann, H.C., T.C. Pagano, S. Sorooshian, and R. Bales. 2002. Confidence builders: evaluating seasonal forecasts from users' perspectives. Bulletin of the American Meteorological Society. 683-698.

Jones, J.W., J.W. Hansen, F.S. Royce, and C.D. Messina. 2000. Potential benefits of climate forecasting to agriculture. Agriculture, Ecosystems and Environment 82: 169-184

Jones, S.A., B. Fischhoff, and D. Lach. 1999. Evaluating the science-policy interface for climate change research. Climatic Change. 43: 581-599.

Lamb, P.J. 1981. Do we know what we should be trying to forecast-climatically? Bulletin of the American Meteorological Society 62: 1000 - 1001.

Lemos, M., T. Finan, R. Fox, D. Nelson, and J. Tucker. 2002. The use of seasonal climate forecasting in policymaking: lessons from Northeast Brazil. Climatic Change 55: 479-507.

Letson D, G.P Podestá, C. Messina, R.A. Ferreyra. Submitted. ENSO Forecast Value, Variable Climate and Stochastic Prices. Climatic Change.

Mason, S.J., L. Goddard, N.E. Graham, E. Yulaeva, L. Sun, and P.A. Arkin. 1999. The IRI seasonal climate prediction system and the 1997/98 El Niño event. Bulletin of the American Meteorological Society 80: 1853-1873.

Meinke, H.W. and R.C. Stone. In press. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. Climatic Change.

Meinke, H.W., W. Baethgen, P.S. Carberry, M. Donatelli, G.L. Hammer, R. Selvaraju and C. Stöckle. 2001. Increasing profits and reducing risks in crop production using participatory systems simulation approaches. Agricultural Systems 70: 493-513.

Messina, C.D., J.W. Hansen, and A.J. Hall. 1999. Land allocation conditioned on ENSO phases in the Pampas of Argentina. Agricultural Systems 60: 197-212.

Mjelde J.W., H.S.J Hill, and J.F. Griffiths. 1998. A review of current evidence on climate forecasts and their economic effects in agriculture. American Journal of Agricultural Economics 80: 1089-1095.

Moser, S. 1999. "Impact assessments and decision-making: How can we connect the two?" White paper prepared for an NSF sponsored workshop on sea-level rise impact assessments in Charleston, SC, 31 January - 3 February 1999.

Orlove, B.S. and J.L. Tosteson. 1999. The Application of Seasonal to Interannual Climate Forecasts Based on El Niño - Southern Oscillation (ENSO) Events: Australia, Brazil, Ethiopia, Peru, and Zimbabwe. Institute of International Studies. Berkeley Workshop on Environmental Politics. Working Paper WP99-3-Orlove. Available from http://repositories.cdlib.org.

Patt, A., 2000. Communicating probabilistic forecasts to decision makers: A case study of Zimbabwe. Belfer Center for Science and International Affairs (BCSIA) Discussion Paper 2000-19, Environment and Natural Resources Program, Kennedy School of Government, Harvard University. Available at http://environment.harvard.edu/gea.

Patt, A., and C. Gwata. 2002. Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. Global Environmental Change 12: 185-195.

Podestá, G. P., C. D. Messina, M. O. Grondona, and G. O. Magrin. 1999. Associations between grain crop yields in central-eastern Argentina and El Niño-Southern Oscillation. Journal of Applied Meteorology 38: 1488-1498.

Podestá, G.P., D. Letson, C. Messina, F. Royce, R.A. Ferreyra, J.W. Jones, J.W. Hansen, I. Llovet, M. Grondona, and J.J. O'Brien. 2002. Use of ENSO related climate information in agricultural decision making in Argentina: a pilot experience. Agricultural Systems. 74: 371-392.

Pulwarty, R.S., Redmond, K.T. 1997. Climate and salmon restoration in the Columbia River Basin: The role and usability of seasonal forecasts. Bulletin of the American Meteorological Society 78: 381-397.

Rajagopalan, B. and U. Lall. 1999. A k-nearest-neighbor simulator for daily precipitation and other weather variables. Water Resources Research 35: 3089-3101.

Roncoli, C., K. Ingram and P. Kirshen. 2001. The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. Climate Research 19: 119-132.

Sarewitz, D., R. Pielke Jr., and M. Keykhah. 2003. Vulnerability and Risk: Some Thoughts from a Political and Policy Perspective. Risk Analysis 23: 805-810.

Satorre, E.H. 2001. Production Systems in the Argentine Pampas and their Ecological Impact. In: Solbrig, O, R. Paalberg and F. Di Castri (eds). Globalization and the Rural Environment. David Rockfeller Center for Latin American Studies, Harvard University, Cambridge, MA, Harvard University Press.

Schneider, S. H., 1995. Evolutionary organizational models for interdisciplinary research and teaching of global environmental change. In: Waddington, D.J., (Ed.), *Global Environmental Change Science: Education and Training,* NATO ASI Series Vol. 129, Springer-Verlag, 9-32.

Sonka, S.T., J.W. Mjelde, P.J. Lamb,, S.E. Hollinger, and B. Dixon. 1987. Valuing climate forecast information. Journal of Climate Applied Meteorology 26, 1080 - 1091.

Stern, P.C., and W.E. Easterling (Eds.), 1999: *Making climate forecasts matter.* National Academy Press, Washington D.C.

Wilks, D. 2000. Diagnostic verification of the Climate Prediction Center lon-lead outlooks, 1995-98. Journal of Climate 13: 2389-2403.

Wilks, D. and C. Godfrey. 2002. Diagnostic verification of the IRI net assessment forecasts, 1997-2000. Journal of Climate 15: 1369-1377.

Yates, D., S. Gangopadhyay, B. Rajagopalan, and K. Strzepek. 2003. A technique for generating regional climate scenarios using a nearest-neighbor algorith. Water Resources Research 39: 1199-1213.