Weather-Related Interests and Concerns

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My interest continues to be promoting and facilitating the use of climate information in the interest of society. The highly pervasive nature of climate translates the use of climate information into a broad array of decision-making-related activities involving the conversion of climate data into information. The main focus here is on that conversion.

Over time, both public and private sectors have made extensive use of climate information in setting policies and design codes, in planning, resource management, environmental assessments, operations enhancement, marketing, etc., to enable society to better cope with both the general characteristics of climate and its damaging extremes. Coping techniques included hazard avoidance and mitigation, engineering around problems, insuring, adapting, and, if necessary, moving. Climate futures were estimated in many of those processes, usually on a statistical, analog, and/or model-derived basis. Conventional climate forecasts were used primarily in resource management and relating tactical planning: their value depended on quality, confidence, need, and applications knowledge.

Climate forecasts that are more relevant, timely, user-friendly and contribute significantly to decision-making would be beneficial to many. As a responsible member of the global community, concerned with the provision of aid and assistance to developing countries, for tactical reasons and as an exporting nation, Canada has a strong interest in skillful climate predictions for all areas of the globe. Statistical significance demonstrated between climate and the occurrence of the El Niño-Pacific-North American teleconnection has stimulated interest in improving prediction of wester water yields and drought. The anomalously warm Great Lakes' climate in the strong El Niño year 1982-83 was touted as mimicking projected climate warming. Possible associations with Arctic ice and with icebergs on the Grand Banks have been explored and prairie agriculture studies are being initiated. At present, there is recognition that El Niño influences Canadian climate in a regional, marginal and quite varied manner; but significant economic or other benefit from such information has yet to be demonstrated.

National climate forecasts exploit all scientific understanding that may contribute to their accuracy, including that of air-sea interactions, cyclical processes, teleconnections, indices, etc. Current three-month Canadian forecasts are based on a mix of statistical and empirical methods, climate models, and study of El Niño and La Niña analogs. That is, the effects of the warm and cold phases of ENSO, including their teleconnections, are implicit in current climate forecasts to the limit that understanding permits. The extension of climate forecasting from seasonal to annual overcomes some past limitations and opens new doors. The user community concern, then, is in awareness and application of opportunities provided by improved understanding of ENSO and other atmospheric phenomena. That task requires communication, innovation, and complementary socioeconomic understanding.

Problems Faced

Understanding and attitudes:

> "It is often assumed that once information is available, it naturally flows to useful outlets: In fact the reverse is much more frequently true -- much of the world's knowledge lies unused behind dams of ignorance, indifference, and inefficiency." (United Nations University brochure)

Benefits and deterrents to use:

That there is great value in the use of climate information, including climate forecasts, cannot be questioned. But, despite the many well-established effects of climate on economies and human activities, the foreseen benefits from climate forecasts have often fallen short or been elusive. Climatologists have claimed climate information is neglected because its intrinsic value is not well known or readily recognized. At times, climatologists are unrealistic, perceiving much value that is very difficult if not impossible to realize. Many uncertainties surround climate data, and there is widespread skepticism about climate forecasts. The weightings of the many factors affecting decision-making -- of which climate is often not the most important -- may trivialize its value. Most decision processes are designed to cope with the normal range of climate. Conventional climate forecasts of a departure from the mean or "coping value," therefore serve a restricted market. They give no indication of the time and magnitude of occurrence of extreme and episodes that will occur within the forecast interval and which are usually the major concern of many decision makers. Extreme-value forecasts, as used in building codes and engineering design, provide another means of coping with climate extremes. They, too, do not specify the time of occurrence, but are precise as to magnitude, e.g., the 1981-84 Great Salt Lake precipitation excess of 1027 mm is a 1:120-year event (Karl & Young, 1986).

The value of ENSO-based forecasts is often alluded to by the aggregation of losses attributed to climate anomalies during strong El Niño periods. As the apparent effects can be quite varied, direct cause-and-effect cannot be established in many cases. Many of the experienced losses may have resulted from inadequate planning, design, and regulation enforcement, or influenced by anomalous antecedent conditions. Nor would skillful forecasts necessarily have enabled all atmospheric hazards to have been adequately addressed. Major climate-related losses occur also in years with no or lesser ENSO events: the 1980 heat wave and drought centered in Texas/Oklahoma ($15 to $20 billion), the January-March "Great Arctic Outbreak" (preceding the 1982-83 El Niño) ($8.2 billion).

El Niño events may contribute to the impact of subsequent climate anomalies as in the 1993 Upper Mississippi Basin flood ($15-20 billion) -- making a case for monitoring evolving conditions (nowcasting). To address all these concerns, decision makers need much more than accurate climate forecasts. They must have related environmental and socioeconomic information and know-how to intelligently act on threats to life and property. To assist them, climate forecasts should be decision oriented, and reflect all important, relevant atmospheric forcings. A perception spawned by some intermediaries is that each ENSO has similar climatic consequences. In Canada, that would be a persistent western ridge during the warm phase. Ridge formation is relatively common, but the climatological pattern east of the ridge can be highly varied from event to event.

Seasonal forecasts of climate states are appreciated and used by the renewable resource-related sectors such as agriculture, water resources, hydroelectric supply and demand, transportation, and tourism season quality and duration. Since the mean relates to seasonal yields and demands, the forecasts can be employed in a stochastic sense, and factored into decision-making, along with production costs, and other less climate-sensitive matters. Farmers give much consideration to forecasts in anomalously wet and dry situations, but their final decision is usually based on last-minute weather, the remaining length of the growing season, and economics. Any increase in skill in climate information will benefit resource sectors in varying ways. For example, enhanced forecasting skill and lead times should result in increased use in setting crop and hail insurance rates: most Canadian companies use an actuarial approach in rate setting, and some crop insurers have neglected climate forecasts because of their need for an annual lead time. Responses to a recent, limited survey of potential Canadian users of climate forecasts are summarized in Table 1. The table does not reflect full potential, since only agencies with a known interest were approached. On the other hand, it does show that the desire for increased skill, lead time, and for information tailored to user activities and models exists. The general public (and, therefore, the mass media) has a strong interest in climate forecasts for planning recreational and other weather-sensitive activities.

Probably the greatest benefits from climate knowledge have been realized in planning and design decisions having a much longer time horizon. Such information is tailored to conform to the decision-making process, i.e., it readily qualifies as "information." Since planning and design rely on long-term climate data series, they may benefit in but a very limited way from improved climatic predictions and knowledge. Recent disasters point to the need for much improved planning, design and construction codes, including steps to have them conform better with societal hopes and aspirations. That capability requires better information, interpretation and delivery on societal as well as structural climatic sensitivities.

1. There must be a payoff:

End-users want climate information to better protect property and life, plan cities, optimize operations, manage resources, insure against hazards, and exploit the favorable opportunities presented by anomalous climate. Their interest in droughts, floods, heat waves,

Table 1. Some Indicated Canadian Requirements for Climate Forecasts[1]

SECTOR	Activity	Information Needed for	Forecast Skill	Area	Duration	Climate Elements
Agriculture	Seeds #	Production	> .8	Regional	1-4 months	p, sun, e, dd, hail
	Chemicals	Insect & disease control		Regional	s/l	patterns of wet, dry, frost
	Chemicals	Weed control /	> .6	Regional	m/s	t, p, humidity probabilities
	Crop & Hail Insurance	Yield and disease assessment		Regional	1 year lead time	hail, drought, wet
	Produce Marketing	re corn, fruit, soybean producers & marketing boards.	> .7	Regional		t, p, soil moisture, frost, wind, hail
	Grain Marketing	Quantitative input to models/indices		Global & Regional	m/s/l	quantitative values of t, p, snowcover
Wildlife	Waterfowl	on-line in map format with data option by biogeographical zones	> .7	Regional	s/l	t, p, seasonal snowfall, snowpack, water levels,
Energy	Supply/ demand			Regional		p, t
Finance	Brokers	commodities, earnings of weather-sensitive companies		Regional		
	Reinsurance	for verification		Regional		Damaging, extreme events
	Banks #	Digital for Energy consumption modeling Commodity and weather-sensitive funds & Farm loans	>.6 to .7	Regional -& population centres	multi-season	elements affecting, energy, commodities & recreation planning
Manufacturing	Beverages	Sales prediction.			up to 12 months	Average t, p, & weekend sunshine,

* m = monthly, s = seasonal, l = longer duration, ** p = precipitation, t = temperature, dd. = degree days, e = evaporation.

Confidentiality a factor. A void indicates no values were specified.

[1]Based on a limited probe of climate forecast needs by agriculture, energy, health, finance and manufacturing sectors by the Canada's Atmospheric Environment Service.

cold, storminess, altered forest fire hazard, soil states and pestilence and cascading socioeconomic effects stems from defending against risks and optimizing on the economic opportunities posed (e.g., altered commodity markets, skiing opportunities and shovel sales). The users are subject to the "bottom line" and purchase information only on the basis of value received. As noted, climate forecasts are but one tool to be exploited and they do not provide desired information on occurrence, intensity, and duration on critical, extreme events.

Climatologists are often visionaries with respect to benefits from new information: users must be introspect and focus on the potential payoff for their often singular application. Since almost any climate variation creates losses and opportunities, society has become relatively well attuned to ways of adapting to, mitigating, and exploiting climate effects through irrigation, crop and site selection, etc. User conversion to new procedures based on enhanced information requires a demonstrable meaningful net benefit over existing practices. The strong linkages between seasonal climate and renewable resources make agriculture, water and energy sectors among those most likely to benefit most from improved climate forecasts. Since significant economic gains are not likely to be sector-wide, but limited to very specific activities, each application needs to be examined systematically. Designers for operations in Beaufort Sea Ice are interested only in increased design hazards, not in reduced ice cover and the related enormous socioeconomic benefits. Land-use planners and managers may find little additional assistance in forecasts not already found in analyzing long-term climate records.

2. *Conventional climate forecast skill*

Widely perceived low skill and lack of familiarity with climatic probabilities is another deterrent to use of conventional climate forecasts. Many decision makers have highly discounted climate forecasts since they can lead to unnecessary action and expense, often resulting in financial loss. Lamb et al. (1984) found accuracies of 70% to 80% were needed for forecasts to be considered useful in agricultural decision-making (users may be satisfied with less (Sonka et al., 1992)). When climate information has a low impact on the process, a mean value of persistence forecast may suffice. The use of persistence and improved understanding in the projected climate forecasts means a superior product, but is its use warranted and convenient in every case?

Probability statistics used in conjunction with forecasts have challenged many would-be end users. Most want numeric values that can be entered directly in their decision-making model without interpretation.

As in weather forecasting, higher-than-average forecast ratings may be possible, or have been alluded to for certain areas, under select meteorological conditions. Such instances have not generally been made known to the user community.

3. Mean-value forecast limitations:

The mean is widely recognized as a fair, general indicator of climate as a resource, but otherwise it has limited value. Anomalies may suggest the direction of variability, and there tends to be a perception in the three-class system that the above and below states have greater variability. Such popular perceptions need verification. The variability of climate within a climate forecast period can be remarkable with extremes and extended episodic anomalies of sign quite different to the forecast value. Their occurrence may not affect the validity of the forecast, but if the user's activity is vulnerable to such variations, it may have little value.

What Is Needed from El Niño Forecasting and Research Communities:

Forecasting:

1. Make well known high confidence, singular opportunities for action, especially when forecasts may have a probability of success above the 0.65 level.

2. Establish standards and clearly communicate levels of skill (correlations, sensitivities, limitations, etc.) to the consumers in his/her language.

3. Improve understanding of the variability of regional climate responses to ENSO.

4. Develop specific applications monitoring, forecasts, advisories or alerts for highly sensitive sectors and times of sensitivity, such as for increased risk to critical environments, crops or economies threatened by flood, drought, heat wave, or other hazardous, episodic events.

5. Support development of user programs that insert climate information routinely into the decision-making process, ensuring attention is given when needed. Such programs should address key sensitivities and critical times, minimize details to be handled by the decision maker, show bounds of reasonable expectations and levels of uncertainty.

6. Collaborate with users and intermediaries in specialized application and tailoring of forecasts to decision-making.

7. Make global/regional forecasts (with generalized interpretations) readily available to alert users to potential risks and opportunities for North American interests abroad.

Communication:

"Inadequate communication transcends all factors associated with the failure to transfer climatic information in an expeditious and effective manner." (Anon.)

1. Analyze needs and how the information is or would be used by major sectors.

2. More vigorous marketing and education. Make available to business, government, resource managers, highly readable, informative, documentation on successes, the circumstance under which they occurred, areas affected, time, duration, intensity, etc.

3. Hold routine information sessions for science writers.

4. Better inform users on limitations on El Niño forecasting globally.

Research:

A. Prediction:

1. Better identify and make known areas/times when there is an unusually high probability of success, and focus on improving forecasting skill for such events.

2. Document and provide information on sensitivities, durations, intensities, timing of anomalies and the variability of ENSO-type manifestations.

3. Improve the match of lead times, content and decision-making.

4. Assess the possibility of El Niños contributing to the clustering of extreme events and, if so, the nature and statistical interpretation thereof.

5. More fully establish the nature (intensities, durations, extent) of El Niños acting alone and the differences resulting from the co-occurrence of dust veils or other physical change that might offset or complement expected effects (attribution).

6. Explore implications of moderate to major ENSOs occurring in conjunction with other major climatic forcings to generate exceptional events comparable to, say, flooding enhanced by perigian tidal forces.

B. Socioeconomic studies:

1. Better identify and make known high payoff, ENSO-related opportunities for loss mitigation, resource exploitation, and applications techniques.

2. Critically assess the role of El Niño-related phenomena in the increasing frequency of natural disasters and propose optimal mitigative measures.

3. Develop more effective procedures for incorporating and adapting newly acquired understanding into decision-making in highly sensitive, major sectors of activity (e.g., models and risk statistics, etc., for agriculture, energy systems, etc.).

4. Develop compatible socioeconomic data bases to advance modeling the effects of El Niño-type events. This would include information on (1) natural resource-based industries such as agriculture and food, hydroelectric power generation, coastal plain degradation, fisheries, forestry, tourism, and (2) human activities in general such as industries, commodity investments, transportation, loans, public safety, health, etc.

5. Increase in-depth studies and model development for socioeconomic consequences noted in the above item 4.

6. Work jointly with agencies/industries most concerned with or affected by El Niño effects, clarifying and making known untapped policy and other decision-making opportunities provided by ENSO-related information (this requires full understanding of the user's decision-making process).

Usable Science:
Thoughts on Improving Decisions with El Niño Information

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Introduction

In recent years policymakers have expressed desire that scientific research show more demonstrable societal benefits, in other words, to be more "usable" (e.g., Brown 1992, Mikulski 1994). Such demands are one consequence of the end of the Cold War, which provided a guiding rationale for U.S. science policy in the post-World War II era. At the same time, budget deficits limit the amount of federal resources designated for scientific research. These twin pressures on the research community will increase demands upon science to demonstrate its value in addressing societal needs.

In spite of policymaker's wishes, the "use" of scientific information is in many instances neither straightforward nor simple. Traditionally, the scientific community has produced information with little, if any, serious or systematic consideration of its use or its users. The guiding principle for users, including sponsors of research, has generally been *caveat emptor* -- let the buyer beware. This paper discusses, and hopes in the process to demystify, the concept of "usable science" through the example of information generated about the El Niño phenomenon, particularly forecasts.

Scientists have discovered that increases in sea surface temperature in the eastern and central equatorial Pacific, called El Niño, and differences in atmospheric pressure between Darwin, Australia and Tahiti, called the Southern Oscillation (SO) are related to various climate phenomena around the world, especially the tropics (Glantz 1994). These interrelated oceanic-atmospheric phenomena are referred to as El Niño/Southern Oscillation or ENSO. Outside scientific circles the terms El Niño and ENSO are often (mis)used interchangeably. The linkages ENSO and weather and climate anomalies across the globe are called teleconnections (Glantz et al 1991). Following the 1982/1983 ENSO many global climate anomalies were attributed, rightly or wrongly, to the event -- more specifically, the U.S. experienced both costs and benefits (Glantz et al. 1987). The ENSO phenomenon provides a prime opportunity for scientists to systematically produce usable information for improved decision-making. Unfortunately, scientific information, per se, is not always usable by decision makers.

Scientific Information

Scientific research results in three interrelated types of information: (a) descriptive, (b) explanatory, and (c) predictive.

(a) Descriptive information is produced from observations of events or some record of a trend or trends. For example, Quinn et al. (1987) combed several centuries of historical records to develop a time series of El Niño events.

(b) Explanatory information relates cause and effects. It can be the documentation of a simple statistical correlation or the development of a full-fledged theoretical understanding. For example, Tribbia (1991) presented a theoretical explanation of observed ENSO-related atmospheric teleconnections.

(c) Predictive information is one result of the application of theoretical understanding. It can be, but is not always, the output of complex models. For example, Barnett et al. (1988) review the results of two statistical models used to forecast the El Niño of 1986-1987.

Such scientific information is generally technical, drawn from an academic discipline, and targeted at a scientific audience. As such, descriptive, explanatory, and predictive scientific information is generally not directly usable by most (potential) users. Scientific information must be further "translated" in the context of the specific needs of particular (potential) users. (It is important to note that not all information can be "made useful" to users. Usability must be "built in" to the research process. See Pielke, Jr., 1994.)

Usable Science

Scientific information can be considered usable when it contributes directly or indirectly to the clarification of a course of action by public or private decision makers -- i.e., individuals, groups, or organizations. More specifically, usable science contributes to (a) issue attention, (b) problem definition, and (c) problem resolution. By itself, scientific information is logically incomplete for a rational decision.[1] A rational decision requires some sense of a desired outcome (i.e, goal clarification) and some range of action alternatives (i.e., response strategies), in addition to descriptive, explanatory, and predictive information (Simon 1981, Lasswell 1971). To say that scientific information is used, is to say that it is associated (directly or indirectly) by an individual or group (i.e., a user) with their goals and with the invention, selection, and evaluation of alternative response strategies in the process of answering one or more of the following questions:

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[1] By a "rational decision" I mean one that is likely to achieve its intended outcome. The social sciences have many alternative conceptions of rationality. See Forester (1984) for a summary.

* What is/are the problem(s)?
* What are our action alternatives in response?
* What is the likely outcome of each possible choice with respect to our goals, and why?
* Based on our goals, what ought we to do?

Each of these four questions is the focus of substantial research activity in the social sciences. It is in the structuring and answering of these questions that the social sciences can help the physical sciences become more "usable" by (potential) users.[2] In the process of problem definition it is of utmost importance to remember that scientific information *alone* cannot

* clarify goals;
* invent action alternatives; nor
* obviate choice.

Values necessary to clarify goals, creativity needed to invent action alternative, and the act of decision lie outside the realm of scientific information, yet can be influenced by scientific knowledge. In addition, values, creativity, and decision can each be studied scientifically. With new knowledge our goals change, new opportunities for creativity arise, and decisions present themselves where they did not exist before (Mesthene 1967). The bottom line is that usable science can only be defined in the context of the goals of a particular user or user community. For this reason, (potential) users and producers of scientific research need to communicate with one another throughout the research process and the process of problem definition and resolution. The following sections attempt to clarify what it means to use science.

(a) Using Science to Bring Attention to Issues

Science often brings "issues" to public attention (Downs 1972, Kingdon 1984). Issues arise when public awareness develops that a "problem" may exist (cf. Rein and White 1977) For example, Glantz (1994, 78) observes that the 1982-83 El Niño event served as a "wake-up call" to societies around the world; in other words, El Niño became an issue. As a result, in subsequent years the scientific community sharply expanded its research efforts into description, explanation, and prediction of the ENSO phenomenon. Generally, outside scientific circles such scientific information is not explicitly associated with specific goals or objectives. That is, issues are not yet defined as "problems."

A "problem" is a perceived difference between how things are and how we would like them to be (cf. Lasswell 1971, 56). Problems do not exist "out there," they must be defined by people in terms of valued outcomes (goals). Once defined, problems lead to demands for action. For instance, when ENSO causes reduced fish populations, it becomes a problem for

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[2] On the "usability" of research see Hayek (1945), Rein and White (1977), and Seidel (1983)

fishing communities -- who value fish for their economy and social well-being -- who then demand some sort of action in response. Problem definition is a necessary prerequisite for effective decision-making. Without a sense of "how things are" and "how things ought to be," actions are likely to be ineffective because they will be poorly focused.

(b) Using Science to Define Problems

From the universe of issues, individuals and groups define problems. The act of problem definition is contextual and subjective. It is subjective in the sense that it is a function of an individual's or group's values or goals. In other words, one's assessment of "how things are" and "how things ought to be" depends on what values one holds. To say that problem definition is contextual means that different situations, especially different values/goals, will lead to different definitions of a problem (Torgerson 1985). For instance, Glantz (1984, 18) observes that "El Niño means different things to different people." It is a problem for some, an opportunity for others, and irrelevant to many.

The significance of the 1972/73 El Niño for different groups in the anchovy industry in South America illustrates subjectivity and contextuality in problem definition (Glantz 1984, 18):

* "To a Peruvian fisherman [El Niño] can be a two-edged sword: a sharp increase in fish catches may be realized for a period of time . . . After a few months, however, the fish population can be sharply reduced."

* "To the Peruvian government, El Niño is a harbinger of bad news. It brings a sharp decline in productivity of the fishing sector. This means that exports and, therefore, foreign currency earnings will drop sharply, causing the government to curtail development programs. This, in turn, may lead to high unemployment in the fishing sector and to labor unrest. . ."

* "To a Chilean fisherman, El Niño can be good news, as changes in ocean temperature may cause pelagic fish populations to migrate south from the usually rich Peruvian waters into Chilean coastal waters."

The Peruvian and Chilean fishermen and their respective governments can be expected to define the problem of El Niño quite differently. For Peruvian fishermen the problem is one of sustainable employment -- jobs and well-being. For the Peruvian government the problem is one of social unrest and national productivity. For the Chileans, the problem is one of opportunity and may include questions of how to deal with its new status as one of the "major fishing nations in the world." The point is that one event, the 1972/73 El Niño, had different effects on different groups, and hence, each defined "the" problem from their particular perspective, including the outcomes which each held as valued (cf. Glantz 1981).

The existence of different, often conflicting, problem definitions has political consequences. Even with the same information, value differences between individuals or groups often result in different conceptions of the existence, severity, or type of problem. Problem definition is further complicated with the existence of uncertain, imperfect, or partial scientific information (Etzioni 1985). Hence, various participants in a political process will appeal to (and often selectively ignore) different scientific data for a host of reasons, e.g., to justify the primacy of their problem definition over others. El Niño is like most issues brought to public attention through scientific research in that there are more questions than answers. Thus, it often seems that "science speaks out of both sides of its mouth about the course that policy should take" (Rein and White 1977, 266). Scientific information is, therefore, used differently by different participants in a political process.

Using Science to Resolve Problems

The most straightforward use of science to resolve problems occurs in cases where a group with shared goals (or an individual) arrives at a consensus problem definition which allows for consideration of action alternatives for decision. In such cases the use of scientific information is largely a matter of information collection and communication. The challenge is to identify appropriate decision makers and to provide them with information, which they can understand and on a timely basis, that helps to clarify choice. For instance, El Niño information may help an individual farmer prepare for an increased likelihood of a seasonal drought or a coffee plantation to hedge against changes in the likelihood of drought or frost. In such cases, it is often possible to model the decision-making process in order to determine quantitatively the value (e.g., in dollars) of additional information (e.g., Stigler 1961).

Yet, even in these most simple of situations realistic determination of information use is difficult. Social scientists have discovered many factors beyond information collection and communication that contribute to the failure to use scientific information and to its use in inappropriate ways. Decision makers "make do" with whatever information is immediately available, when time and other resources are limited (Lindblom 1959). Instead of optimizing their decision routine, they "satisfice" themselves with the first acceptable solution (Simon 1981). Furthermore, uncertainty, ambiguity, routines, rules, and complexity all contribute to misuse and even the nonuse of potentially useful information (March 1981). Decision makers can also use information to justify inaction or decisions that have already been made. Often, decision makers gather more information than they actually need in the hope that a "magic bullet" solution will be discovered or to avoid unanticipated surprises (Feldman and March 1981). The process of information gathering itself has intrinsic value to some decision makers (e.g., "at least we're doing *something*") (Feldman and March 1981), particularly in issues related to science and technology (Clark and Majone 1985). Sometimes, additional information is irrelevant to problem definition or to problem resolution. Awareness of how information is actually used in specific processes of decision in the real world is a first step toward better understanding how scientific information can lead to improved problem definition and decision-making.

Assessment of ENSO information use is one way to towards a better understanding of its potential contribution to decision-making. Murphy (1994) identifies two approaches to assessment of weather and climate forecast value which can be summarized as use-in-theory and use-in-practice.[3] Use-in-theory refers to efforts to estimate the "value of forecasts under the assumption that the decision maker follows an optimal strategy" (Stewart 1995, 40). Generally, economists, statisticians, and decision theorists share expertise in assessment of use-in-theory (e.g., Winkler and Murphy 1985). Use-in-practice refers to efforts to understand how decisions are actually made in the real world, and the value of forecast information therein (e.g., McNew et al. 1991). Political scientists, sociologists, and psychologists are examples of those with expertise in assessment of use-in-practice. Such assessments can be used to assess the usefulness of descriptive and explanatory ENSO information as well as predictive information such as ENSO forecasts.

Politics becomes a factor in information use in situations where different groups with different goals define problems in a number of different ways. Politics is a general term for the reconciliation of competing interests (Schattschneider 1976). In the United States competing interests are reconciled under the provisions of the Constitution. Scientists are often dismayed and sometimes appalled that their research is used to buttress opposite extreme positions in policy debate. In the hope of avoiding this situation, scientists and policymakers join together to reach a "consensus" of scientific opinion. Unfortunately, the process of science is such that, generally, the information that scientists are able to reach a consensus on is always the most useful to decision makers. As Rein and White (1977, 266) note, "if a problem is clear, uncontested, and unvalued, it ordinarily does not emerge at high levels of political debate." They argue that "political choices can only be articulated but never resolved by the provision of scientific information." Hence, it is likely that ENSO research can be used by participants in a decision process to obscure problems as well as to clarify them.

Finally, information is often used by some to gain a competitive advantage over others, i.e., knowledge is power. In the marketplace, such competition is expected and normal. In society more broadly, systematic informational advantages are problematic: It can separate the "haves" from the "have nots." For instance, suppose that El Niño information is found to systematically benefit corporate agriculture over the individual farmer, resulting in a competitive advantage to the corporation. This may or may not be socially desirable. Information is intrinsically neither democratic nor equitable. In other words, part of the process of assessing the potential or actual value of the use of research output is to assess winners and losers and the resulting implications for society more broadly.

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[3] Murphy (1994) calls these *prescriptive* and *descriptive* assessments of forecast value. Glantz (1976) uses the terminology of "what ought to be" and "what is."

Conclusion: Prospects for Improved Use of ENSO Information

Based on the discussion in this paper, ENSO information can become usable science in three different ways. It has potential to contribute to issue attention, problem definition, or problem resolution. In practice, however, determination of actual and potential ENSO information use in the contexts of (a) issue attention, (b) problem definition, and (c) problem resolution is a difficult task. Realistic assessment of the usefulness of existing or additional research requires careful attention to actual processes of decision in order for the full potential of usable science to be realized.

A research program targeted at producing usable ENSO science might proceed along the following steps. The first step is to assess past use of ENSO information in specific contexts:

* Identify users and non-users of El Niño information;
* Identify what information was used (misused and not used) and for what purposes;
* Evaluate information use.

A record of past use will provide precedents and opportunities missed which can be used to help identify potential users of ENSO information, their needs, and potential problems that they face.[4] Usable science depends upon close interaction of researcher and user from program planning through implementation of usable output. Thus, it is of utmost importance that future research efforts include users and potential users in program planning and implementation. It is also important to have a link, such as that provided by the social sciences, between the information producer and user to facilitate the process of producing usable science.

Once past uses and needs are identified, the program would next focus on the production of new information, e.g., new research findings. To be most useful, new ENSO information would contribute to the asking and answering of the following questions in each relevant context:

* Are there problems? For whom? What are they?
* What are possible action alternatives?
* What other information is needed/desired for problem clarification/definition? Is it available?
* What are the consequences?

These questions are extremely difficult to answer in any context, and only the beginning of a difficult iterative process of creating usable ENSO science. Because usability is contextual,

[4] A step in this direction is provided by Lagos and Buzier (1992).

user needs will vary according to their various problems. What works in one place or at one time may not work in another place or time. In some cases, ENSO information will be irrelevant to the resolution of a problem. In other cases, ENSO information may be a key to improved decision-making. There will be no simple "magic bullet" solution to the needs of all potential users of ENSO information, and there is no one methodology to make ENSO research more "relevant." Usable ENSO science will result from the close interaction of scientists, social scientists, and information users.

To the extent that scientific research is supported for purposes other than science, it is appropriate to refer to the product of such efforts as "usable science." Usable science begs the questions that issues of science and policy require to be answered for improved decision making: Usable by whom? How? And for what purpose? Usable science is neither the self-evident product of scientific discovery, nor the sole responsibility of potential users. Usable science will only result from the interaction of scientists and users working to identify, define, and solve particular problems facing the broader society. As public and private decision makers, we face increasing complex issues and problems. Our ability to deal with them will depend a great deal on our ability to better use the science that society has worked so hard and so long to achieve.

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Weather, ENSO, Climate Change Predictions and Socioeconomic Impacts

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Let us consider a single point on the planetary surface. The weather and climate at this point will be influenced by a combination of local effects (radiation balance and the hydrological cycle) and by the physics and dynamics of the global system. The seasonal/solar cycle, an outcome of the orbital characteristics of the Earth-Sun system also plays a dominant role. The average weather and climate conditions at this hypothetical point, together with other factors such as soil, nutrients, topography and water availability will determine the type of plant and animal life that can flourish or survive. The same holds for human activity. The plant, biological and human life styles existing at this point would have adapted (approximately) over the years to these average conditions -- or they would not be there. This simple rule is somewhat obscured by technology which introduces the possibility of existing at this point even under adverse conditions.

Let us ask the question "why should we be interested in the average weather and climate at this point?" Social and economic systems would be in equilibrium with their respective environments. They would not be the same at all points, but nevertheless be in some form of equilibrium. Indeed, the average state of any system would be of little interest and of little practical value, unless we speak of completely unexplored regions of the Earth. There are two basic reasons for the pervasive interest in weather and climate. The primary reason, I believe, for this interest and sometimes even fear is on account of the possibility of unpredictable "change" from "normal" conditions. The second reason stems from development and existence of fairly advanced technological infrastructures at least in the developed countries of the world. That is, transportation, food, water and energy distribution systems and trade can support a society with supplies far away from its location. However, this comes at a price and an increased dependence on resources that are not locally available. With such dependence comes vulnerability to not only local changes but also weather, climate, social and political changes occurring at great distances (even global) from the "point" under consideration.

The social and economic impacts of a weather, ENSO or climate system event (i.e., a significant deviation from "normal" conditions) can be highly nonlinear and very large depending on the relative timing of an event and its intensity, magnitude or deviation from normal. For example, a small change in the timing of rain relative to planting (e.g., a delay of one week in the beginning of the rainy season) could, in some places, mean the failure of the entire crop for the year. With better technology (irrigation and crop varieties) potential impact can be averted, but only up to a point. Beyond certain thresholds, extreme events on weather time scales, persistent anomalies on seasonal to interannual time scales (this includes ENSO), or a shift in the "average" conditions (climate change) can have significant and very large social and economic impact.

Thus, the prediction of "change" on all time scales becomes a central resource management problem and economic issue. Uncertainty in a prediction can become a serious problem for managers and decision makers. A wrong decision can be costly. If the uncertainties associated with a prediction are too large, the tendency is to ignore the prediction or take no action until a better assessment is available on how the environment is changing or evolving.

For any prediction to be of practical value, lead time (advance warning) is necessary. The lead time needed is not a function of the physics or dynamics of the system alone. It also depends on the time it would take to mobilize equipment, people, funds and other resources to prevent an event from occurring, if possible, or mitigate the impact of an event. For example, the impact of extensive flooding or protracted extreme cold weather could be substantially reduced if flood control walls are built or if coal and oil supplies are stockpiled before the event. Taking such action is costly and typically needs lead times of a few months to a year. Thus, forecast lead times of that order are necessary with sufficient reliability to activate preventive measures. Uncertainty in a forecast forces a probabilistic evaluation of risk factors and cost. The insurance sector is, of course, familiar with these calculations. However, even in that industry a shift in the frequency of natural disasters can push the limits of the system's ability to handle claims. This apparently has happened over the past five years with the California earthquakes, Midwest flooding and Florida hurricanes, among other extreme events.

The El Niño-Southern Oscillation (ENSO) is considered to be one of the largest anomalies in the climate system with a recurrence frequency of approximately two to seven years. Though the ENSO signal is strongest in the tropical Pacific, and the event considered to be largely on account of instability in the coupled atmosphere-ocean system in the Pacific, the atmospheric circulation changes accompanying an ENSO are global in scale. With increasing spatial and time scales, atmospheric and climate system anomalies are usually associated with correspondingly larger social and economic impacts. In the case of ENSO, impacts are global -- a well-documented fact.

As regards to El Niño forecasting, there are several aspects which need to be kept in mind. To properly qualify as a forecast, the El Niño, an event whose duration is 18 to 24 months, should be predicted at approximately 18 to 24 months before -- even this would place the forecast in the category of a two-day forecast in the context of weather time scales. A three to six month El Niño prediction begins to approach a "nowcast." A one month prediction would definitely fall into the category of a nowcast, because there would already be several major indicators showing a tendency toward El Niño conditions. Subsequent to this initial precursor phase of an El Niño it becomes more of a monitoring exercise than a forecasting matter.

Notwithstanding the above, even nowcasting (three months lead time) an El Niño would have substantial planning, management and practical decision making value, if the "cast" is accurate in terms of the El Niño's magnitude/intensity, duration and potential impact areas. This is because there would still be sufficient time to implement a decision before the event peaks. The present knowledge (including that encapsulated by a coupled system model) of the ENSO, however, is insufficient to make precise predictions of these three elements even after the onset of the event. By this statement I do not mean to diminish the progress made in ENSO forecasting over the past ten or more years. Rather, it points out the complexity of the Earth system and to some unquantifiable extent the absence of the physics of processes in the models and in our understanding of ENSO.

ENSO is a more complex phenomenon than previously thought. While statistical analyses have shown that there is coherence in several areas in the global signature of temperature and precipitation anomalies during an El Niño, each El Niño appears to impact even these sensitive areas quite differently. The data availability (i.e., time series) precludes a statistically rigorous analysis of, for example, the differences in the impact of strong or moderate versus weak El Niños. Nevertheless, I believe that carrying out such an analysis would be a very useful research investigation. Uncertainty in El Niño forecasts and associated impacts can also arise on account of the fact that other non-El-Niño related Earth system dynamics could influence or even dominate the weather in any particular area even during an El Niño year and in an "El Niño impacted area." Examples of other global system features that need to be considered are the previous season and year's snow cover, soil moisture, sea ice, ocean circulation, and some speculate momentum budget and Earth rotation.

The possibility of a change in the frequency and intensity of El Niños associated the "global climate change" also needs to be investigated. The Southern Oscillation and some SST indices have been more or less anomalous, almost continually, for the past four or five years. There are also indications that even the globally averaged surface temperature (ocean and land) may have gone through a "level" shift. That is climate change may not be a gradual change. In fact, historical evidence generally indicates that "change" occurs in abrupt shifts and jumps. If, indeed, El Niños are more frequent or ENSO like states the "new normal" condition, then the governments of many countries could begin to develop management strategies to accommodate such a change. More time, research and analysis is needed to investigate the possibility of a change in the frequency and nature of the ENSO phenomenon.

In conclusion, I believe that with more research and observations, ENSO nowcasting skills will improve over the next decade. By this I include model predictions with a three to six or nine month lead time. However, much more complex system dynamics would need to be understood and modeled before true prediction skills improve. Particularly important will be information on when the next El Niño will occur (i.e., with lead times of over two years), its intensity/magnitude, duration, and importantly the type and distribution of its impact. Also difficult will be the assessment of the frequency of occurrence of El Niños under a "changing" global climate scenario. From a practical point of view, however, simply being able to classify in advance an El Niño as strong, moderate or weak, and being able to separate (or as the case might be, combine) the direct impacts of an ENSO from or with other weather/climate and socioeconomic features will be of immense practical value.

ENSO Information and Proprietary Economic Interests: What is NOAA's Responsibility to the User Community?

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Hippocrates wrote that, "there are in fact two things, science and opinion; the former begets knowledge, the latter ignorance" (Jones, 1923, v. II, p. 265). Sir Francis Bacon (1688) observed that, "knowledge is power." Just as science begets knowledge, science begets power (Price, 1965; Commoner, 1966). Information can deliver economic (and other) power to those who possess it. This holds true in the case of ENSO information as well as any other type of knowledge. A central question that may be raised, then, is: what is the responsibility of NOAA for providing relevant ENSO information to existing and prospective users? This author takes the position that NOAA's responsibility is limited to dissemination and general interpretation of ENSO information, except in those cases where users volunteer to reimburse the agency for additional analysis and/or geographic specificity of related climate impacts.[1]

ENSO information can provide a competitive economic advantage to some parties who use it. Improved long-range ENSO forecasts would also be beneficial to some actors, depending on the economic activity in which they are engaged. Yet the potential value of ENSO information is not evenly distributed among economic sectors and different users within particular sectors. For activities that involve long lead-times for planning and/or implementation (e.g., agriculture, energy contracts), ENSO information could help decision makers adjust their present and future behavior (e.g., purchasing, seed selection) in order to mitigate economic loss or even to sustain a profit, or reinforce plans and decisions already made. For activities such as commercial marine fishing, knowledge of possible or actual changes in ocean currents could provide a competitive advantage to a few, some or all boat captains--depending on how widely the information is distributed, how reliable decision makers think the information is, and how much freedom individual boats have to fish in particular waters.

Most economic activity in the international marketplace, however, involves competition with others (except where trade barriers and protective tariffs still exist). Since information about the global climatic impacts of ENSO events is a form of competitive

[1]The issue of "interpretation for hire" raises an entirely different (but associated) question about the agency's liability if forecasts turn out to be inaccurate and economic losses are incurred by users due to decisions based on agency interpretation of ENSO information. Another question relates to the appropriate limit(s) of government involvement in private sector economic decisions.

power, an economic actor may establish a "proprietary" interest in that information. A proprietary interest means to possess some degree of ownership over something.

Since knowledge is power (or competitive advantage), it is not in the self-interest of decision makers who find advantage in ENSO information to share that information, inform competitors of the value of such information, or even advise competitors that he/she is actually making use of particular types of information. Instead, some users who find value in ENSO information will essentially treat that information as a "trade secret" or the equivalent of a copyright or a patent, which is not to be shared with competitors.[2]

An illustration of proprietary economic interest in climate information comes from the Coho salmon fishing fleet off the coast of the state of Oregon. A researcher involved in a 1973 coastal upwelling experiment observed that fishing boats tended to congregate in areas with a narrow range of water temperatures and adjacent to upwelling areas near the Oregon coast. Subsequently, an experimental pilot program was undertaken to determine if sea surface temperatures and 24-hour weather forecasts could be communicated to the salmon industry to help fishermen identify local environmental conditions conducive to Coho concentrations. While the experiment was deemed a *technical* success by researchers, forecasters and many fishermen, some in the commercial fishing industry expressed hostility to continuing the issuance of same-day fishing forecasts. According to one report (NSF, 1974, p. 33),

> Some fishermen were firmly opposed to the [fish forecast] program. Generally, they felt that such a system would benefit the less efficient fishermen at the expense of the more experienced fishermen.

The same economic perspective on proprietary interest in information was repeated twenty years later in an ENSO workshop report, but with an implied conclusion that ENSO information would be intrinsically beneficial to *all* users (IAI, 1994, p. 24):

> Industry often worries that release of [ENSO] information might compromise its economic position, so companies need to be convinced that this is not necessarily the case and that cooperation will benefit society in general and ultimately, them as well.

Clearly, weather and climate information is seen by some as possessing an economic value. This helps to explain why investment firms that trade in weather- and climate-sensitive commodities (e.g., coffee, cotton, grains, natural gas) and banks that provide loans to weather- and climate-sensitive economic sectors employ their own staff meteorologists or hire their own consultants. It also helps to explain why in-house use of weather and climate

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[2]An example of a commercial trade secret is the well-protected, original recipe for Coca Cola, which is locked away in a guarded vault in Coca Cola's corporate headquarters in Atlanta.

information is not openly discussed or compared by users in specific economic sectors and why it is difficult to place a monetary value to a national economy of the availability of weather/climate information.

Given the proprietary interest that economic decision makers have in information that may be used to competitive advantage, what is the responsibility of a public agency such as NOAA with respect to dissemination, availability, interpretation and relevance of ENSO information? The agency's responsibility is limited to ensuring dissemination and availability unless individual members of the user community are willing to pay for "value-added" interpretation and/or analysis. The problem here is that unless the agency is very familiar with the "particular circumstances of time and place" of individual economic decision makers (Hayek, 1945, p. 524), interpretation/analysis may approach the expression of opinion, which begets ignorance. Instead, Hayek (1945, p. 524) argues that "ultimate decisions must be left to the people who are familiar with these circumstances, who know directly of the relevant changes and of the resources immediately available to meet them."[3]

The agency's responsibility, then, is to ensure the availability of ENSO information, perhaps distributing it not only to those requesting it, but also to government repository libraries, trade associations, and so forth. The paternalistic attitude reflected in the IAI quotation cited above should be carried no further than to ensure information availability and scientific interpretation.

ENSO information should be treated by the public agency as is census information: disseminate it and let others make use of it for their own purposes in their particular circumstances of time and place. As with various government census reports, ENSO information will not be of equal value to all parties all the time--or even at the *same* time. It is not government's obligation to try to interpret ENSO information for every conceivable user in a climatic version of a national industrial policy. Rather, it is the self-interest of private decision makers that will motivate them to find what is valuable to them in the ENSO information placed in the public domain.

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[3]An example of circumstances of time and place is the recent executive order signed by U.S. President Clinton declaring four California counties eligible for federal disaster aid in the aftermath of the continuing effects of El Niño on this year's Coho salmon fishing season, which extends from 1 May through 31 October 1994 (White House, 1994). Local efforts were mobilized to link ENSO to adverse economic conditions defined by both spatial and temporal circumstances.

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