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A Conceptual Framework for Enhancing the Utility of Rainfall Hazard Forecasts for Agriculture in Marginal Environments

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Abstract. Semi-arid and dry sub-humid areas (especially in the tropics) are characterized by high inter-annual and intra-seasonal rainfall variability. Agriculture, which employs the bulk of the rapidly increasing populations, is largely rain-fed, low-input based and highly resource dependent. Recent spates of drought have, therefore, exacerbated the now-too-familiar specter of famine and starvation in these areas with glaring examples being the recurring episodes in sub-Saharan Africa since the great Sahel drought of 1969–1973. A great need for accurate and timely hazard forecast products in aid of agriculture thus exists.

Several schemes are currently employed by various agencies around the globe in this direction. There does remain, however, a gap between product provision and user expectations. This paper examines this gap suggesting a five-point framework within which it can be addressed as an action agenda for the climate science community. The paper posits that changes are possible to existing methodologies (related to three of these points), which, within the context of current science, can greatly enhance the utility of forecast products for agriculture in marginal areas. The remaining two points have, however, been identified as requiring additional applied research and necessary pointers for addressing these issues are provided. First is the need for appropriate impact-related indicators for intra-seasonal and interannual rainfall variability that are easy to compute, amenable to forecasting and follow closely the experiences of farmers in marginal areas. The second is a consideration of appropriate forecast information formatting and communication medium that guarantee effective feedback between forecast producers and users. Specific examples of the status quo and of work currently underway are cited from southern Africa – a region currently attracting international attention as a result of recent droughts and the threat of famine.

Key words: drought definition, drought indicators, seasonal rainfall forecasts, climate forecast utility, agricultural applications, conceptual framework, emerging research agenda

1. Introduction

Recurring droughts in semi-arid and dry sub-humid areas (especially in the tropics) characterized by largely rain-fed, low-input based and highly

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resource-dependent agriculture have exacerbated the now-too-familiar specter of famine and starvation. A glaring example of this is sub-Saharan Africa, which has witnessed repeated devastating droughts since the great Sahel drought of 1969–1973. Socio-economic development here, as in similar areas, depends to a large extent on the availability and use of accurate and timely climate forecast information. The application of seasonal climate forecasting for agriculture, however, faces significant challenges even as the field of forecast applications research is evolving (NOAA-OGP, 1999; IRI, 2001). Hooke and Pielke (2000) propose that one reason why challenges persist despite tremendous investments in the science and technology of weather and climate forecasting in recent years is because the weather prediction enterprise still functions "like a symphony orchestra without a conductor." Different players in the forecast production, dissemination and use process, operate with diverse sets of goals, and have, as a result, diverse viewpoints and methodologies. This has brought about a situation where the same issues have different meanings for different people and are discussed from widely differing perspectives. For example, even though there is a general concern about the problem of drought and its impacts on the livelihoods of resource-dependent people in dry, semi-dry or dry sub-humid environments, there is no agreement on a simple definition. Consequently, how it is to be measured and indicated and how its onset, duration and intensity are forecast and the information communicated (effectively) to the user are anything but consensually agreed-to procedural matters.

As long as these views and goals remain at odds, forecast information may continue to be underutilized by vulnerable groups to reduce the negative effects of survival-threatening climate variability (Lemos *et al.*, 2002). To bring about the desired change, Pielke and Carbone (2002) propose the evolution of the needed "conductor" in the development of an integrated perspective about this important enterprise, incorporating all key players. A successful accomplishment of this task will, however, require a clear understanding (and possible restructuring) of the operational framework within which the three most important groups of players (forecast producers, information disseminators and end-users) interact as well as of the conceptual issues that surround their differing expectations. This is the starting point of this exercise, for which the ultimate goal should be the convergence of scientific outputs and users' needs – an achievement that, as Stern and Easterling (1999) noted, can increase the utility of forecasts.

In this paper, the focus is on characteristics of seasonal forecasts in the context of what they are meant to offer to the agricultural sector vis-*à*-vis user needs. Emphasis is placed on farmers as important end-users of seasonal forecast products. Gaps in the forecast system are described from the perspective of climate forecast producers, and a proposed framework within which to address them is considered. An attempt is made to demonstrate the potential utility of the suggested approach with illustrations from initial research results over southern Africa. The paper concludes by highlighting ongoing work, as well as some components of what is seen as an emerging research agenda in this area.

2. Gaps in Existing Practice: Forecast Producers – User Needs

User surveys illustrate that providing total monthly/seasonal amount of precipitation as the only parameter in a seasonal forecast simply does not accommodate the needs of key agricultural users. For example, at the annual regional agrometeorology workshop held from November 11 to 15, 2002 in Harare, Zimbabwe, delegates representing agrometeorology and agronomy from 12 countries in the southern African region diagnosed the state of the seasonal climate forecast system in their countries. Each country team described their current seasonal climate forecast system, the main gaps in the current system as it served agriculture, and some of their recommendations to improve the system in the future. Emerging common findings and recommendations were instructive.

All delegates identified critical weaknesses in their seasonal forecasting systems. Most particularly, they all indicated that current rainfall forecasts be expanded and requested that forecasts provide an indication of temporal distribution of rainfall throughout the season (SADC-RRSU, 2002). As a specific recommendation, country teams asked that forecast producers further develop seasonal forecast models to provide:

- intra-seasonal temporal distribution of rainfall
- earlier preliminary seasonal forecasts;
- downscaled, area-specific rainfall amounts; and
- temperature forecasts.

(SADC-RRSU, 2002, pg. 3)

Also, recently, a study in Limpopo Province, South Africa (Archer 2003), surveyed resource poor farmers in a former homeland area. Researchers asked farmers which parameters they would consider most important were they to receive seasonal climate forecasts. Fig. 1 shows the relative proportions of farmers desiring total precipitation amount versus season onset ($n = 46$). It is important to note that all farmers indicated willingness to accept the seasonal total rainfall forecast should it be made available. Farmers were also extremely specific as to how they might use the forecast, including strategies for early planting, cultivar choice and more competitive marketing. These positions support those of delegates representing research and operational work in forecast application who met at the Communication of Climate Forecast Information workshop in

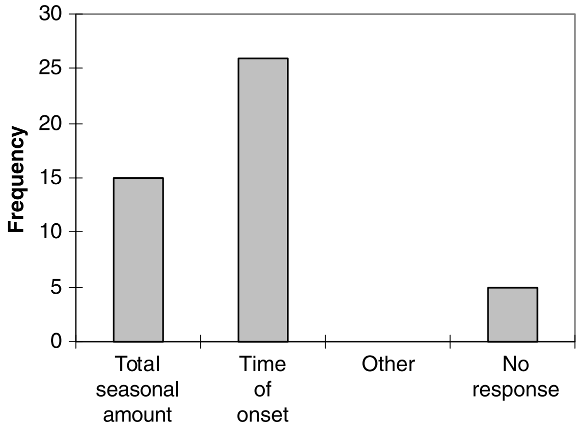

Figure 1. Type of forecast desired by small-scale agriculture user group, Limpopo Province, South Africa.

Palisades, New York, from June 6 to 8, 2001. In plenary, a number of participants specifically called for season onset information to be provided by forecast producers. It was noted that forecast producers as a group really need to know that users demand forecast parameters over and above seasonal averages even though climate science may not be currently robust enough to make such parameters available (IRI, 2001). Delegates noted that

> "It is clear that the system has not adequately allowed for feedback on specific forecast characteristics of value to users to reach the forecast producers. Also, the demands of climate information accuracy and reliability are apparently not yet reconciled with the demands of users." (IRI, 2001, p. 42)

How has such a gap, or mismatch, between forecast producers and users emerged and, more specifically, why has it not been systematically communicated to forecast producers as a critical concern? Lemos *et al.* (2002) provide a useful perspective in this regard. They contend that seasonal forecasting faces a "new technology adoption" problem (p. 480), where the potential uses and limitations of the technology are not fully understood and that distinct "cultures" exist in forecast application, where scientists and policy makers are subject to substantially different sets of rules and goals. It is no surprise therefore that, even in the assessment of the value of forecasts, users and policy makers have more interests in the practical results (profit and reduced expenditure or losses) while scientists tend to be more concerned about the technical state of science (Lemos *et al.*, 2002; Pielke and Carbone, 2002).

In this way, seasonal forecasting suffers from what Lemos *et al.* (2002) refer to as ‘‘new tool blues’’ (p. 481) – as a new technology, policy makers and end-users will have high expectations of its benefits (particularly in an area such as the southern African region where climate variability can have substantial negative effects). New technologies require, however, time to adapt to effective and appropriate uses (Lemos *et al.*, 2002), and we would propose that the mismatch in terms of user requirements for forecasts of the temporal distribution of rainfall illustrates that this adaptation process remains in its early stages. Be that as it may, if forecasting is to serve farmers or any other user group, it must be based on a foundation provided by answers to three basic questions: (1) What information does the user need (as primary requirement) or want (as secondary requirement)? (2) How is this need to be met (weighed against what can realistically and confidently be made available)? (3) When is it to be met?

Herein lie the greatest challenges in improving forecast utility. Below, a suggested path to accomplishing this is presented as an urgent action agenda for the climate science community.

3. An Agenda for Action: Elements of a Conceptual Framework

The gaps that exist between forecast-product provision and use, are not, it is important to state at the outset, completely unknown to climate scientists (forecasters to be specific). They have remained unaddressed only because forecasters have yet to find satisfactory answers to the second and third questions raised above, of how and when user needs can be effectively met. This has led to the classical response that current science does not allow for the provision of service beyond current practices.

This paper posits, however, that current science is not as big a limiting factor as such a response implies. The most important limiting factor appears to be the understanding of the framework within which seasonal forecasting needs to take place in aid of agriculture. The current situation in which forecast information, even if accurate, may or may not explain all agricultural impacts, does leave room for improvements in service delivery even as research necessarily advances new scientific frontiers. The basic elements of an appropriate framework can be deduced from answers to the following fundamental questions: (1) What do we understand by rainfall variability and its impacts on agriculture? (2) What is the best yardstick for measuring this variability and its impacts? (3) What variety of information can forecast statements optimally contain? (4) What is the most appropriate indicator of this variability that can be forecast? and, (5) What is the most appropriate format and medium for communicating a forecast information?

These elements, as described hereafter, are not exhaustive but are considered representative of the challenges that need to be met to increase the potential utility of forecast products to farmers. Where necessary, existing practices in southern Africa – an area where recent agricultural droughts have contributed to the current threat of famine and starvation – are used for illustration.

3.1. DEFINITION AND SCOPE OF RAINFALL VARIABILITY IN RELATION TO AGRICULTURE AND OTHER SECTORS

Of the two extremes of variability in rainfall, drought and floods, the former constitutes the most significant threat to rain-fed agriculture (being critical to rural livelihoods across sub-Saharan Africa). This is not only because droughts have occurred more frequently in the last few decades (Ward, 1998; Richard *et al.*, 2001), but also because a drought episode is a creeping phenomenon, the onset of which is usually slow. An important element in understanding droughts and their impacts therefore remains the determination of each episode's onset from which its duration and intensity will subsequently be determined. This represents the first challenge, as the determination of the onset is a function of how an episode is defined and what is taken as its scope. Since many definitions of drought have been proposed, whichever is employed, will have a bearing on how an episode is seen to evolve and how its impacts and associated implications are viewed, assessed and understood.

There are four main definitions of drought in the literature: agricultural, hydrological, meteorological and socioeconomic (e.g., World Meteorological Organization, 1975; Wilhite and Glantz, 1985; American Meteorological Society, 1997). Two key points are worthy of emphasis.

First, agricultural droughts specifically relate to the availability of rainfall measured against the requirement of crops within the course of the growing season. They are therefore short term, encompass the amount as well as the distribution of the rainfall received, and could be described as associated more with the quality rather than the quantity of rainfall. Hydrological droughts differ in that they are related to reduced discharge in rivers and streams as manifestations of sustained, long-term water (rainfall) deficits. These drought types are, nevertheless, similar as they directly describe the impacts of water deficit in two of the most important sectors of human–environment interactions. Meteorological droughts, on the other hand, only express a deficit of rainfall relative to an expected amount over a given time regardless of association with an activity.

Second, these forms of drought have a natural sequence of occurrence. The agricultural occurs first before the meteorological, followed by the hydrological. Drought episodes also come to an end in the same sequence. Thus, a hydrological drought in any season is usually associated with agricultural and meteorological droughts. However, it is possible to record agricultural droughts several times in a given season even when neither meteorological nor hydrological droughts can be said to have occurred at the end of the season.[1] Socio-economic droughts, or more appropriately, impacts, as a fourth category occur as a result of the inability of the affected people to cope with drought.

Whereas our primary target is the agricultural sector, our operational practice in seasonal rainfall forecasting utilizes an understanding of rainfall variability that is purely meteorological. The assumption is that once defined meteorologically, sector-specific impacts can be deduced for agriculture and water resources. As the foregoing arguments show, this is far from the truth. A meteorological drought definition can explain hydrological (and some socio-economic) impacts because it utilizes rainfall information on shorter timescales that can be aggregated to the larger time period. It cannot, however, always explain agricultural impacts that are generally of a shorter duration even though their accumulated impacts may be long lived.

In short, the impacts of droughts vary from sector to sector. To understand these impacts, the definitions adopted have been sector specific. Thus, many researchers have proposed different methods for assessing and monitoring different drought types. See recent reviews by Heim (2002) and Keyantash and Dracup (2002). However, the fact that the main forms of drought occur in sequence, according to the quantity of rainfall and the duration of the impacts associated with its deficit, presents an opportunity for a unified definition. Redmond (2002) has suggested a simple but appropriate definition as "insufficient water to meet needs." It should be possible in this context, to view all forms of water deficit as integrated occurrences such that other forms of deficit are simply progressively more intense forms of agricultural drought.

As alluded to earlier, socio-economic impacts should not be seen as the last drought type in a continuous sequence of droughts, that is, agricultural drought > meteorological drought > hydrological drought > socio-economic drought. They are, and must be viewed, as manifestations of the occurrence of deficits in water requirements associated with human activities, principally (but not restricted to) agriculture and water resources. This is presented schematically in Figure 2. Climate variability causes short- and

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[1] At the Sixth Southern African Regional Climate Outlook Forum (SARCOF-6) in September 2002, many SADC member countries' reports of the prior season (2001/2002) reflected agricultural drought (largely due to early cessation of the 2001/2002 rainy season). Little to no meteorological drought was reported, however, and the focus of predictions for the southern Africa region remains based on a meteorological drought definition.

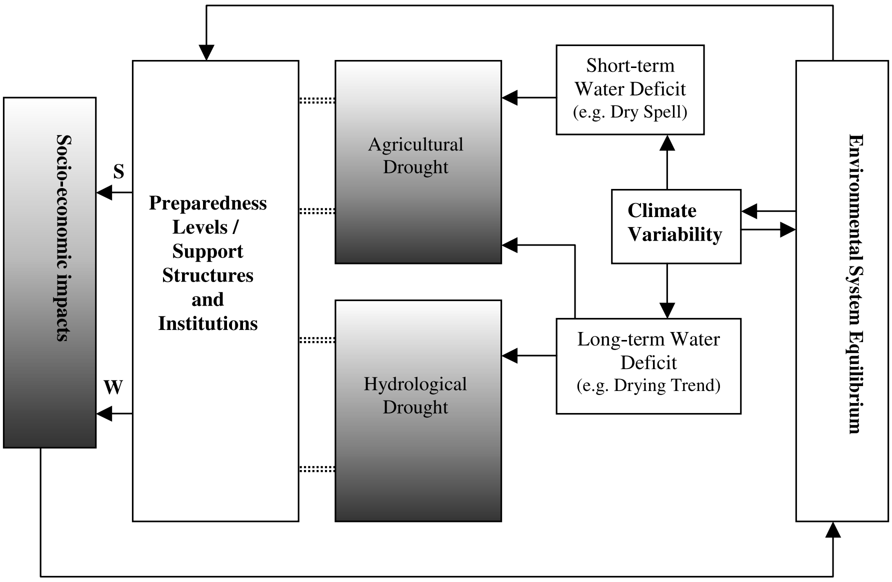

Figure 2. Schematic representation of linkages between drought types and socio-economic impacts. 'S' and 'W' represent strong and weak support structures, respectively. The intensity of the shades in the shaded boxes indicates level of severity.

long-term changes that result in water deficits manifesting as agricultural and hydrological droughts. Droughts translate into socio-economic impacts according to their severity, the level of preparedness and adaptive capacity of the people concerned and the strength of support structures and institutions within the society that could cushion negative effects. Where these structures are strong, vulnerability levels are low and socio-economic impacts are minimal. These impacts are serious where the support base is weak and could translate easily into increased demands on the environmental resource base in resource-dependent areas. Long-term climate change could also directly impact on existing environmental equilibrium. The diversity, quantity and quality of the resource base determine the viability of support structures by influencing what avenues for productive engagement or alternatives are available.

Droughts are important, therefore, not just as meteorological phenomena but also because they impact upon human well-being and push the environment toward degradation. Accurate and useful climate forecasts, when properly communicated, can provide a means of helping affected people cope with these impacts through informed responses. The process of forecast support resulting in informed responses to impacts is represented by the thicker arrows in Figure 3. Such coping strategies, where they are successful,

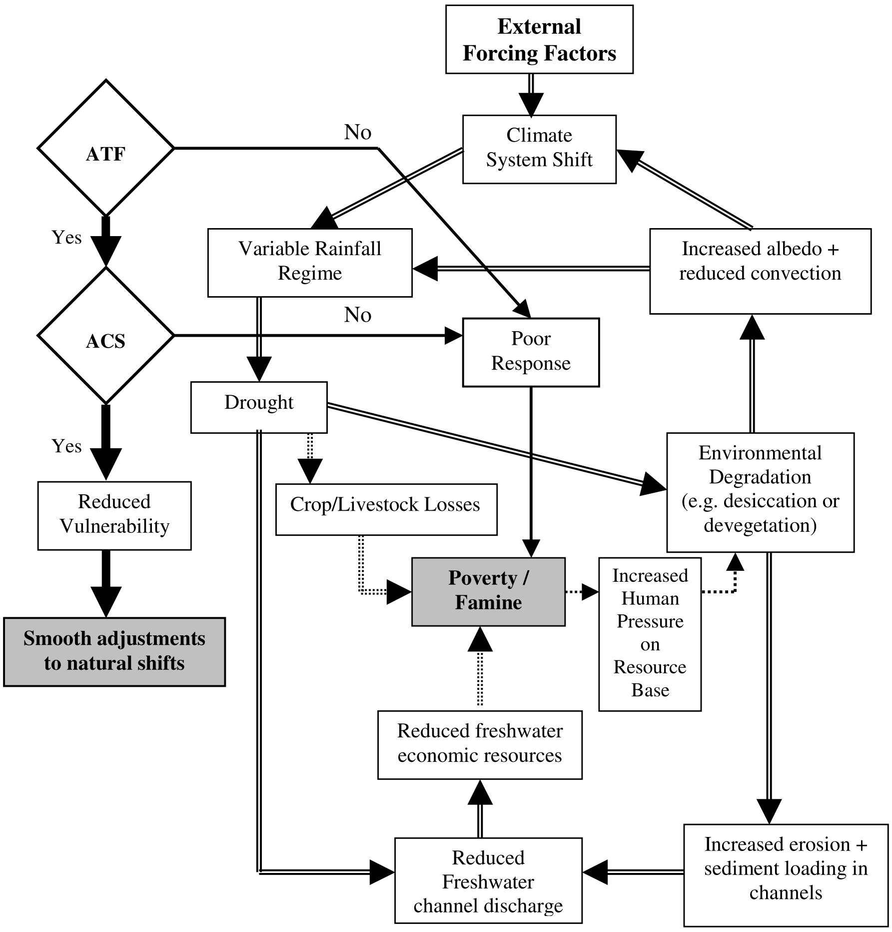

Figure 3. Detailed sketch of potentially self-sustaining feedback linkages between the environment system, drought occurrences and socio-economic impacts in a resource-dependent semi-arid or dry sub-humid area and the role of Accurate and Timely Forecasts (ATF). Double and single lines are natural and human processes/consequences, respectively. Where dashed, lines indicate links that ATF and Appropriate Coping Strategies (ACS) can break.

sustain not only human survival, but also the coupled human-environment system, within which negative feedback mechanisms between drought, poverty and environment may otherwise develop, as shown on the right hand side of Figure 3. In other words, in the absence of appropriate coping solutions, drought occurrences in marginal areas can accentuate socio-economic hardships. Socioeconomic stress may then result in increased anthropogenic pressure on already fragile ecosystems. Thus, droughts can lead to more environmental degradation that may, in turn, induce further droughts (by altering rainfall regimes through land-use change) or heighten the impacts of subsequent ones. This unifying perspective is an important prerequisite for operational high utility seasonal forecast products as it conditions how we measure droughts and their impacts in rain-fed agriculture.

3.2. APPROPRIATE YARDSTICK FOR MEASURING RAINFALL VARIABILITY AND ITS IMPACTS ON AGRICULTURE

Having examined the definition of "drought" and associated impacts in the context of rainfall variability (which we seek to forecast) and available environmental resource base, the next logical step is to determine how best to measure this variability for agricultural purposes. Because agricultural droughts are a function of the availability of water to crops at the right quantity and time, they are influenced by a variety of weather elements (rainfall, temperature, evaporation, humidity, wind speed, etc.) in addition to soil type and moisture content. Several methodologies for assessing agricultural droughts have attempted to combine as many of these variables as possible. Even though the resulting quantities may be useful tools for intra-seasonal monitoring of crop development and for crop growth and yield modeling, their utility for seasonal forecasting is not certain. It does seem logical that in the context of seasonal forecasting, some of these variables may be unnecessary duplications of others. Timely operational availability of information on all the variables may also be an important hindrance especially where most are only available over large areas as algorithm-driven indirect satellite estimates often involving unreasonable but inevitable simplification (Byun and Wilhite, 1999). As highlighted in Section 3.5, techniques that are overreliant on "expert-inputs" suffer a disconnection when it comes to functional linkages between forecast producers, disseminators and users.

Luckily, these tools are not necessary as yardsticks for defining or assessing agricultural droughts at the seasonal level. Some studies (e.g. Alley, 1984; Oladipo, 1985) have found that multivariable indicators do not do any better than measures based entirely on rainfall. Redmond (2002) advanced the same opinion that the use of temperature in the Palmer Index family adds very little information and could safely be left out. The challenge can therefore be stated as the development of rainfall-only measure(s) of agricultural drought that indicate not the quantity, but the quality of rainfall. In doing so, however, it is important to note that as shown in Figure 2, agricultural drought could be both short term and long term. Thus, tools are required to measure both aspects. Short-term drought conditions can evolve and disappear quickly and cannot therefore be well observed over long durations e.g. from season to season.

3.3. FORECAST INFORMATION CONTENT – REQUIREMENTS AND POSSIBILITIES

As indicated in Section 3.1, agricultural droughts have more to do with the quality of rainfall than its quantity. Thus, information on the onset, intensity, duration and cessation of an episode are required in this context if they are to be relevant to farming operations. It is also pertinent to note that whereas information on these components of a drought episode can be made available as monitoring tools, drought science and (consequently) seasonal forecasting practice are still far from adopting them as seasonal forecasting variables. Be that as it may, there is more to rainfall variability than seasonal totals alone, such that we are left with a lot of room for improving current practices for the benefit of agriculture. What is being provided now as the seasonal forecast is the magnitude of rainfall departure from mean – a quantity with little or no bearing on crop performance and farming operations within a season. To be of use to the rain-dependent farmer, information on rainfall variability must incorporate thresholds of both quantity and distribution. The argument in the climate forecast community that variables such as rainfall distribution cannot be incorporated into operational forecasting based on the current state of science simply underscores the fact that new perspectives and/or tools are required. The greatest challenge, however, does appear to be the provision of these tools without disrupting existing practice. The levels of expertise and experience developed over the years are valuable assets in this quest for better results and should not be discarded through sweeping changes to procedures (assuming these were possible). New tools must therefore be amenable to adaptation into the existing practices such that change is a gradual process.

Accomplishing this does not require decades. Once the logic is correct, combined measures of rainfall variability are possible by fusing two or more parameters together into indices such that the basic character of each is captured. Such techniques are not new to climatology. For example, a good starting point could be the combination of characteristics of rainfall relevant to agriculture (such as rainfall onset, its distribution, seasonal total and patterns of dry spell events) into some measure of quality instead of considering these as three distinct variables. It is proposed that the perspective that additional characteristics would complicate the number and variety of predictor variables has constituted one of the major stumbling blocks to improvements in the seasonal forecasting system. Integrated indicators of rainfall variability that incorporate all the required characteristics are therefore important ingredients in the task ahead. Existing indicators of rainfall variability are discussed in this context in Sections 3.4 and 4.

In addition to seasonal rainfall total and distribution, the beginning and the end of the growing season are also tractable. This has already been demonstrated operationally over the Amazon and the West African monsoon regimes (Omotosho, 1990; 1992; Omotosho *et al.*, 1999, Sarria-Dodd and Jolliffe, 2001; González and Barros, 2002; among others). In southern Africa, this is an area of current research (Tadross *et al.*, 2003).

3.4. APPROPRIATE INDICATOR(S) OF RAINFALL VARIABILITY

In the light of the arguments raised in Section 3.2, multivariate indicators do not appear to be the best use of resources and will thus not be examined in any detail here. It suffices to state that, recently Heim (2002) and Keyantash and Dracup (2002) provided interesting reviews of some indices available in the literature distinctly for meteorological, hydrological and agricultural droughts monitoring or assessment. This categorization clearly illustrates the influence multiple drought definitions have had on directing impacts research since the middle of the last century and reinforces the need as stated earlier, to re-examine the framework within which they were developed and are expected to be used. To put existing rainfall-only indicators into the perspective of this article as outlined in Sections 3.1–3.3, their weaknesses are worth noting.

Byun and Wilhite (1999) examined the following rainfall-only indices: the Bhalme and Mooly Drought Index (BMDI; Bhalme and Mooly, 1980), Decile (Gibbs and Maher, 1967), National Rainfall Index (RI; Gommes and Petrassi, 1994), Percent Normal (PN; Willeke *et al.*, 1994), Rainfall Anomaly Index (RAI; Rooy, 1965) and the Standardized Precipitation Index (SPI; McKee *et al.*, 1993, 1995) among others and report a key shortcoming as the utilization of data at monthly or longer time frames, thereby failing to clearly separate between the shorter- and longer-term precipitation deficits. This makes them unusable to track or assess agricultural droughts especially those related to short-term rainfall deficits. Also reported, as significant shortcomings, are the absence of a time-dependent reduction function to estimate current water deficiency and the inability to indicate drought severity and its duration. These comments are significant not only because these indices are widely used today, but also because they represent some of the best tools introduced in the last half century (Keyantash and Dracup, 2002). Byun and Wilhite (1999) proceeded to introduce several new indices for objectively quantifying daily drought severity. Of the new indices, the Effective Drought Index (EDI) that could be computed over 14- and 365-day periods to indicate agricultural and hydrological impacts, respectively, were rated the best. Even though additional verification is desirable, the use of daily rainfall data in these indices makes them potentially highly informative rainfall-only drought monitoring tools.

One drawback these novel tools (EDI) share in common with other indices, however, is the reliance on departures from long-term mean as a basis for indicating deficit rainfall. A mean state is usually conditioned by data length and quality that vary widely from place to place and influenced by several factors differently over different time periods. Any measure of departure from it therefore is an inherently unstable quantity spatiotemporally. Over large parts of sub-Saharan Africa where information needs in support of agriculture are greatest for example, the lack of good quality data amplifies these weaknesses in methodology often contributing to differences between what "climate experts" see and what farmers experience.

In summary, in addition to certain specific drawbacks, all the indicators covered by these reviews are measures of the quantity rather than the quality of rainfall. They are therefore not suited to agricultural applications (in the context of this framework). Research to develop efficient rainfall-only indicators of quality needs to be intensified to satisfy this requirement.

3.5. INFORMATION DISSEMINATION: FORMAT, MEDIUM AND FEEDBACK

As has been repeatedly elaborated, climate information needs to be specific to agriculture before it can be expected to be of use to the farming community. But even the best of information can be of little or no benefit if it is not communicated properly. Thus, the format in which climate information is presented and the medium through which it is delivered and responses to it are received, are crucial in enhancing its utility.

In this regard, the utility of forecast information should be assessed based on its ease of interpretation directly in terms of impacts on specific sectors (Redmond, 2002). Thus, the inappropriateness of the current practice of communicating rainfall forecast as "above-normal" or "below-normal" has been highlighted in Section 3.3 and a review of available alternatives provided in Section 3.4. An additional important format-related issue is the timing of the specific elements of information required. When can/or will the information on onset date, on cessation date and other indices of rainfall quality be made available and in what form to serve the best interest of the farmer according to the limits imposed by current science? This question is pertinent since the time lag between the development and receipt of forecasts helps determine their utility (Murphy *et al.*, 2001) and is to be addressed in the context of each rainfall regime. It will require research linking adopted indicator(s) to potential predictors to identify signals with a good enough lead time to facilitate early warning advantages to farmers. This may be addressed once the issues in the preceding sections are successfully overcome. A suggested appropriate layout is illustrated for southern Africa in Section 4.

In the meantime, it is important to note that seasonal forecasting over southern Africa only covers expected seasonal total issued for two equal halves of the summer season; October–December (OND) and January–March (JFM). The OND forecast is issued in September and the JFM forecast in December when the earlier forecast is reviewed. In other words, only one of four critical information elements is provided, and this is not in synchrony with important farming decisions and actions. Thus, even though each forecast is issued by consensus and the forum where this takes place is multi-sectored, the agricultural sector remains unsatisfied as noted in Section 2. The adopted timing format (OND and JFM) and the sharp boundaries between them are not the dictates of the limits of science as forecasters tend to suggest in the choice of rainfall total as the only predictor. Furthermore, atmospheric dynamics (like any other natural phenomenon) indicates no sharp, discontinuous boundaries in its variability at particular times. On the contrary, evidence suggests that over southern Africa, weather-producing systems go through a seasonal rhythm of transition from spring through summer to autumn (See Tennant and Hewitson, 2002).

The timing format does appear in the light of the foregoing to have been based on the convenience of scheduling meetings for forecast issuance and on the perception from a forecast producer's perspective of when the rainfall season starts. This should be redressed if progress is to be made. Current-science-permitted alternatives are examined in Section 4.

4. Putting the Pieces Together

The elements of a framework, within which the goal of bridging the gap between forecast products and user requirements in agriculture could be achieved, have been described in the foregoing sections. At this juncture, it is pertinent to state that while the issues raised in Sections 3.1–3.3 may be merely procedural or conceptual and could be handled in the context of current science, those raised in Sections 3.4 and 3.5 would require new applied research and tests before operationally applicable answers are available. These outstanding challenges are collapsed into two research questions as follows:

- Research question 1: What rainfall-only indicator(s) do we employ for rainfall variability at the intra-seasonal and interannual levels in the context of agriculture that can also effectively cover other impact sectors and will be amenable to seasonal forecasting?

Of the indices reviewed under Section 3.4, only the EDI (Byun and Wilhite, 1999) satisfied a key requirement of the same index incorporating monitoring and assessment potentials. However, in addition to the shortcomings discussed earlier (chief amongst which is that they are measures of quantity and not quality of rainfall), these indices are rather complicated to compute – a characteristic that could limit their ease of use (see Keyantash and Dracup, 2002). The search for easy-to-use, forecast-amenable agricultural monitoring and assessment tools therefore continues. It is in this regard that, among several similar thrusts around the world, a group at the University of Cape Town is working on an index for measuring the quality of rainfall, termed the Rainfall Quality Index (RQI), an improved and a more robust form of an earlier index, the Monsoon Quality Index (MQI; Usman, 2000). RQI is computed on a simple premise that determines the quality of seasonal rainfall (with respect to agriculture) as a measure of total seasonal rainfall, its intra-seasonal distribution and the number of dry spells within the season. The index, as a combination of these quantities, differs from each and results in a parameter more closely related to the experiences of farmers. Some of its teething problems are being identified, but its ease of computation and interpretation and non-reliance on long-term mean, are novel and could represent a way forward for rainfall variability research in agricultural applications. A detailed description of the index and its variants (for assessment and monitoring) as well as initial results of verification tests over southern Africa are being compiled for publication (M.T. Usman *et al.*, in preparation). More stringent verification tests are planned for assessing its operational potential.

- *Research question* 2: What changes to the existing dissemination format and medium will bring about effective two-way communication between forecast producers and users?

With respect to information formatting, it has been reported that farmers are not happy with the “above” or “below-normal” nomenclature currently in use. This should change even if the probabilistic forecasting paradigm used for forecasts does not. As indicated in response to the first question, new research frontiers are emerging with respect to the assessment and forecasting of rainfall variability that have the potentials of being more end-user-friendly. Greater efforts should be invested in this direction. The possibility of having the same easy-to-compute index (ices) as tool (s) for assessment and monitoring of agricultural droughts presents an opportunity for a more integrated forecast system in which all players can communicate more effectively. Extension workers could, for example, be in a better position to explain forecast products to farmers, conduct growing season drought monitoring and assess forecast accuracy directly in terms of impacts.

Even as research reveals more avenues for system improvement, it is pertinent to note that a forecast remains prone to limitations imposed by the chaotic nature of atmospheric systems. This demands that any forecast system must allow for the review and updating of forecast statements at regular intervals to maximize its utility. At present, more needs to be done in this regard in many regions. In West Africa for example, a forecast for the onset of monsoon and total rainfall during July–September (JAS) peak-monsoon season is issued in May and reviewed in July. This may still be far from the

Table I. Suggested improved seasonal forecasting layout for southern Africa

Rainfall phase	Cropping phase	Approximate calendar months	Most important parameter	Issuance	Update	Review
Onset	Sowing	October–December (OND)	Start of growing Season	August	October	December/ January
Peak	Pollination	December–February (DJF)	Total + distribution (Quality)	October	December	February/ March
Cessation	Ripening	February–April (FMA)	Effective end of season	December	February	May

ideal requirements of the end-users, but it is more informative than the current procedure in Southern Africa. Here, onset date is not forecast, and the two half-season total rainfall forecasts are issued before and midway through the summer, prior to each season.

The authors are convinced (in agreement with results of end-user surveys) that forecasts should be issued in line with the key phases of the farming season, namely: sowing, pollination or flowering, and ripening or harvest. The timing of the consensus forecast for each of these phases should then allow for "rolling" or interwoven issuance, updating and verification. A suggested "rolling-phases" format for southern Africa is shown in Table I. Such an intricate array of activities will, facilitate more effective communication and permit the evolution of a better forecast system. Implementation will, however, not be easy. It will require dedication of research energy supported by financial resources to hold four or five meetings in a year to issue or review forecast statements. Dutton (2002), in stressing the need for constantly improving the forecast system, has suggested that key players must pull their energies together to pressure governments into providing more logistic and financial support. Perhaps, this may only be necessary as part of a learning process, as further research may void the relevance of repeated meetings.

5. Summary and Conclusions

Recent fluctuations in rainfall regimes over many arid/semi-arid or dry sub-humid areas and the associated threats of famine, starvation and mass wasting of human populations, have underscored the need for reliable climate forecasts in aid of agriculture. Many operational dynamical, empirical or combined schemes are in place in this regard in many regions (see reviews by Goddard *et al.*, 2001; Murphy *et al.*, 2001; Palutikof *et al.*, 2002) but the failure thus far to dampen the incessant complaints from user-groups is a pointer to the problems still plaguing seasonal forecasting as a system. These problems have arisen from differing sets of goals between forecast producers and users (Lemos *et al.*, 2002) and a perception by which producers treat droughts as purely meteorological phenomena. It is assumed that user-specific impacts are implied in any forecast and these are to be deduced by intermediate specialists. In this setting, any shortcomings are blamed on the inevitable inherent errors in the business of forecasting a chaotic atmosphere.

It is submitted that even though forecast accuracy may still leave room for improvement, there exists a fundamental error in the framework within which the forecast system operates. Five key components of this framework have been identified, and the conceptual and procedural issues surrounding them discussed. New applied research frontiers with respect to two of these components have the potential of changing seasonal forecasting practice. These needed improvements cannot come too soon for many drought-prone areas, especially in sub-Saharan Africa, but will require, as Dutton (2002) notes, resources that the climate forecast community would have to obtain, in partnership with the users of forecasts.

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