THE INTERNATIONAL RESEARCH INSTITUTE FOR CLIMATE PREDICTION
LINKING SCIENCE TO SOCIETY

IRI TECHNICAL REPORT NO. 04-04

Climate Variability and the Millennium Development Goal Hunger Target

September 2004

THE EARTH INSTITUTE
COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Image Credit: **Quintiliano Dos Santos, International Federation of Red Cross and Red Crescent Societies (IFRC)**

The IRI was established as a cooperative agreement between U.S. NOAA Office of Global Programs and Columbia University.

Climate Variability and the Millennium Development Goal Hunger Target

JAMES W. HANSEN
MAXX DILLEY
LISA GODDARD
ESTHER EBRAHIMIAN
POLLY ERICKSEN

International Research Institute for Climate Prediction
The Earth Institute of Columbia University
Palisades, New York, 10964, USA

IRI Technical Report No. 04-04

September 12, 2004

The IRI was established as a cooperative agreement between
U.S. NOAA Office of Global Programs and Columbia University

Abstract

Climate variability contributes significantly to poverty and food insecurity. Proactive approaches to managing climate variability within vulnerable rural communities and among institutions operating at community, sub-national, and national levels is a crucial step toward achieving the Millennium Development Goal of eradicating extreme poverty and hunger. Climate variability can impact a household's access to food by affecting subsistence production, income from primary production, local food prices, and sometimes the economy of an entire region. The risk of household food insecurity is determined by the success of livelihood strategies in the face of climate and other shocks. Across the economy, climate variability affects food security through its influence on investment, adoption of agricultural technology, aggregate production, market prices and economic development, and hence the ability of individuals, communities and nations to produce and purchase food. The impacts of climate variability are both *ex post* – losses that follow a climate shock – and *ex ante* – opportunity costs of conservative risk management responses to climatic uncertainty. The report summarizes the scientific basis, current methodology, and prospects for improving climate prediction at a seasonal time scale. Current forecast methods give modest to moderately-high prediction skill in "hunger hotspots" in East, West and Southern Africa, and other regions in the tropics and subtropics. Applications of climate information contribute to a comprehensive strategy to combat hunger. First is the use of seasonal climate prediction in early warning systems to guide interventions to avert food crises. Second is the use of climate information to manage risk in agricultural systems within vulnerable rural communities and among a range of institutions. This includes smallholder farmers who comprise the largest group of poor and food-insecure; intermediary institutions that interface with farmers, and can provide the information, technical guidance and production inputs required for effective climate risk management; and institutions that make climate-sensitive decisions at a broader scale that influence food security. We also discuss measures to strengthen institutional capacity and coordination to improve management of climate variability. Improved management of climate variability has appealing synergies with other interventions that target hunger, including soil fertility management, small-scale water management, markets, and extension and communication systems.

1. Introduction

Climate is the statistics of weather integrated over time. The atmosphere fluctuates across a continuum of time scales, ranging from daily weather to long-term climate change. *Climate variability* refers to time scales ranging from months to decades, falling between the extremes of daily weather and the long-term trends associated with climate change. The hazards and uncertainty associated with climate variability contribute significantly to both transitory and chronic poverty and food insecurity. The poor and food-insecure who depend largely on rainfed farming for sustenance and livelihood in high-risk environments are among those most affected by climate variability. We argue that, with appropriate policies and institutional support, they are also particularly well poised to benefit from improved management of climatic risk through use of climate information. Advances in prediction at the seasonal (i.e., several months) time scale, in particular, offer potential that is still under exploited. Developing flexible, proactive approaches to managing climate variability within vulnerable rural communities and among institutions operating at community, sub-national, and national levels is a crucial step toward achieving Millennium Development Goal 1, "eradicate extreme poverty and hunger," and a foundation for coping with the uncertainties of a changing climate into the future. This report summarizes the influence of climate variability on hunger, and then outlines a strategy for climate risk management to advance the hunger component of the first millennium development goal.

We address the role of climate variability and climate information in reducing food insecurity and hunger in three areas. One area concerns the use of seasonal climate prediction in early warning systems to avert food crises. Early warning of adverse climate conditions, when combined with effective responses to stabilize household food consumption, can prevent cyclic depletion of household assets and impoverishment. The second area concerns the use of climate information to manage risk in agricultural systems at multiple levels. Staple food markets depend in poor countries depend on local and regional agriculture, often under rainfed conditions. Farmers often constitute the largest poor, food insecure group, and they routinely make climate-sensitive production decisions that could lead to better outcomes when guided by information about climate variability. Opportunities exist for using climate information for decision making at a larger scale – for example, to manage road maintenance programs, grain reserves, commodity markets, reservoirs that provide irrigation water, and other climate-sensitive activities and systems that indirectly affect household food security. We also discuss measures to strengthen institutional capacity and coordination to improve management of climate variability.

2. Livelihoods, Food Security and Hunger

The role of climate in creating or preventing hunger can be induced from a theory of food insecurity causality based on livelihoods.[1] This theory explains why some households experience chronic or

---

[1] The theory and methods are described in http://www.fews.net/livelihoods/framework and Dilley and Boudreau (2001). These trace how natural hazard events and other shocks translate into household food insecurity and hunger outcomes through their effect on the workings of the food economy, following Sen (1981).

episodic hunger and allows specific causes – climatic and otherwise – to be identified. A household can be said to be food secure when it can meet 100 percent of its annual food intake requirements. By this definition, being food secure does not necessarily mean that all members of the household are adequately nourished, just that the household has access to the minimum number of kilocalories necessary for adequate nutrition throughout the year. Households that consistently cannot meet the minimum requirement are likely to experience chronic hunger; those that can only do so part of the time are likely to experience hunger episodically; those that can meet their minimum food intake requirements throughout the year are food secure and therefore do not experience hunger due to lack of access to food.

Although food security by this definition is an absolute – the ability to obtain 100 percent of annual household food intake requirements – food security is also a matter of degree. Households with sufficient resources to obtain 200% of their annual food intake requirements, for example, are more food secure than households that can barely obtain 100% after fully exercising all available options.

2.1. Climate impacts on household access to food

Households obtain food either directly, by producing it themselves, or through exchange. For this reason, hunger and poverty are closely intertwined. Assessing how climate affects the food security of a particular household requires identifying the production and exchange options a household exercises in order to obtain food. For example, in an average year a household may be able to grow enough crops to meet a portion of its minimum food intake requirement. It may also obtain cash with which to purchase food from selling labor, through petty commerce and remittances. The number of kilocalories that can be obtained by exercising these options can vary throughout the year according to resources the household allocates to them as well as to changing external constraints. Therefore the maximum kilocalories that a household can obtain may vary throughout the year as well.

Climate variability can affect how much food households can obtain, especially in economies with a high dependence on primary sector activities. For example, the number of kilocalories that can be obtained through crop production may increase or decrease due to crop responses to rainfall variations. Similarly, the amount of food a household can purchase may be limited by price fluctuations created by rainfall-related variations in production and therefore of food supply. Rainfall variations can affect livelihoods through impacts on trade, such as in the case of livestock trade bans imposed by Middle Eastern countries on the Greater Horn of Africa due to rainfall-related outbreaks of Rift Valley fever, a mosquito-borne virus. Epidemic malaria triggered by climate fluctuations can affect household labor capacity and therefore households' ability to produce food or generate income to exchange for it. Locust outbreaks and migratory patterns also depend on climate conditions. Extreme climate events such as drought and floods can have widespread covariate impacts. A flood, for example, can cut off access to markets by damaging or destroying transportation infrastructure, wash away crops and inundate houses, damaging or destroying a wide range of private and public productive assets. A drought can lead to crop losses, food price increases, reduced agricultural wages and lost revenue from secondary processing and transport of agricultural commodities. Thus, household food security is variable, responding to fluctuations in external factors such as income-generating opportunities, food production and prices – some of them driven by climate variability and others not. Given the range of available livelihood options, households may or may not be able consistently to obtain 100% of their minimum food intake requirements.

2.2. Climate variability and household food insecurity

Risk refers to variability or uncertainty of outcomes, and the resulting likelihood of experiencing a particular adverse outcome such as food insecurity. *Risk management* refers to strategies to avoid adverse outcomes while pursuing positive goals.

Households experience the outcome of food insecurity when they are unable to meet 100% of their food requirements. The risks of household food insecurity, leading to hunger, are determined by the success of household livelihood strategies in the face of exogenous shocks and other pressures to which they are exposed. After exercising all available production and exchange options, some households are unable to meet 100% of their annual minimum food intake requirements. Such households are structurally food insecure. For them, the risk of becoming food insecure has already been realized. Members of such households are likely to experience chronic hunger and will continue to do so unless new opportunities are created for production or exchange or their food supply is subsidized with external assistance. At the other end of the spectrum are households that are very unlikely to become food insecure. These households have enough options for obtaining food that they are unlikely to fall below the minimum threshold. For them, the risks of becoming food insecure, or falling below the minimum food intake requirement threshold, are low or negligible. In between the states of categorical food insecurity and food security are households that are barely or circumstantially food secure, that is, barely or circumstantially able to meet 100% of their minimum annual food intake requirements. These households are at risk of experiencing the outcomes of food security and hunger and may or may not do so depending on changing circumstances. The likelihood of households in this category failing to meet 100% of their minimum annual food intake requirement is governed by two sets of causal risk factors. One set of risk factors comprises the exogenous hazard events or shocks to which the households may be exposed. The other set is the endogenous characteristics of the households and specifically of the livelihood options available to them for obtaining food. The combination of exogenous hazard events or shocks with endogenous vulnerabilities causes losses of production or exchange-equivalency when a hazard event or other shock occurs.

Household vulnerabilities are contingent on the types of hazard events and other exogenous shocks to which a household may be exposed. For example, a household with a high dependence on rain-fed subsistence crop production is vulnerable to drought. If that same household is in a region of high rainfall variability, the combination of probable exposure to drought with the household's vulnerability to drought from dependence on rain-fed crops creates risks of the household becoming food insecure. A household with a high dependence on income from mining is not vulnerable to drought. In this latter case, however, fluctuations in the prices of mineral commodities on international markets could constitute a food security hazard.

In many parts of the semi-arid tropics climate is highly variable, fluctuating according to quasi-periodic changes in global sea surface temperatures and atmospheric patterns, such as El Niño and the Southern Oscillation. In Africa, areas of highly variable rainfall include the Sahel, the Greater

Horn and Southern Africa. All of these areas have been at risk, or have realized the risks, of widespread, prolonged famine associated with drought in combination with the vulnerabilities of household and national economies.

2.3. Climate impacts on agriculture and development

Across the economy, climate variability affects food security through its broader influence on investment, adoption of agricultural technology, aggregate food production, market prices and economic development, and hence the ability of individuals, communities and nations to produce and purchase food. The impacts of climate variability are both *ex post* and *ex ante*. *Ex post* impacts refer to the losses that follow a climate shock. Climate extremes such as droughts and floods, when coupled with vulnerability to these hazards by exposed communities and infrastructure, take a direct toll on lives, health, livelihoods, assets and infrastructure that contributes to food insecurity and poverty. *Ex ante* impacts refer to the opportunity costs associated with conservative strategies that risk-averse decision makers employ in advance to protect themselves from the possibility of climate shocks. Disentangling the ex post and ex ante impacts of climate variability is difficult from a methodological standpoint. A 1980-2000 study of Zimbabwe communal farm households suggested that approximately one third of a 46% reduction in 50-year wealth accumulation was due to actual ex post losses associated with climate and other fluctuations, whereas two thirds was due to ex ante responses to associated uncertainties (Elbers et al 2003).

2.3.1. Ex post losses associated with climate shocks

Through a combination of hazard exposure and vulnerability, poor countries experience climate-related disasters disproportionately. For example, from 1990 to 1998, poor countries accounted for 94% of the world's 569 major natural disasters and 97% of disaster-related deaths (Easterly, 2001), most associated with climatic extremes. In the distributional pattern of these losses, smallholder farmers in particular face substantial climate-related livelihood risk. Climate variability is arguably the dominant source of consumption risk in smallholder rainfed agriculture, particularly in dryer environments (Rosenzweig and Binswanger, 1993; Dercon, 2002; Zimmerman and Carter, 2003). Climate variability drives price variability in regions where markets and transportation infrastructure are poorly developed (Zimmerman and Carter, 2003). In southern India, the coefficients of variation for total annual and net farm income over 10 years were 40% and 127% respectively, due primarily to climate variability (Walker and Ryan, 1990; Rosenzweig and Binswanger, 1993).

Within farming communities, because the relatively poor have less capacity to buffer against climate risk through own assets or financial markets, they tend to experience disproportionate livelihood risk in the face of climate variations. For example, from household survey data from six villages in Sahelian Burkina Faso, Carter (1997) estimated average coefficient of variation of farm income at 25%, leading to food shortfalls in one out of every five years for the average farmer. Farmers in the bottom quartile of land holdings experience shortfalls in four out of five years, while the top quartile of farmers experiences food shortfalls in only one out of ten years.

When households are subjected to severe livelihood and food security stress, they may liquidate productive assets such as livestock or land in exchange for food, default on loans, withdraw children from school to work, or engage in exploitive environmental management practices in order to survive. Abandonment and permanent migration to urban centers or refugee camps is an extreme example. Even if the household weathers the crisis, it emerges more vulnerable to the next shock until lost assets can be restored. Households that are vulnerable to climate shocks, such as droughts, heavy rains and flooding, may therefore successively lose ground economically with each new event. Dercon (2004) showed that a substantial portion of the immediate impact of the drought of the early 1980s on farmer income and consumption persisted for more than a decade in a sample of six villages in Ethiopia.

2.3.2. Ex ante costs of climate uncertainty

For smallholder rainfed agriculture, climate variability is a significant barrier to investment and adoption of technologies that have the potential to enhance production and livelihoods. Poor farmers prepare for the possibility of climatic shocks by employing conservative risk management strategies ex ante that buffer themselves against climatic extremes, but at the expense of low average productivity and profitability, and sometimes inefficient and even exploitive resource use. Farmers' ex-ante responses to risk include: avoidance of improved production technology (Kebede, 1992; Marra et al., 2003), selection of less risky but less profitable crops (Dercon, 1996) or cultivars (Morduch, 1990), under-use of fertilizers (Bliss and Stern, 1982, Ch. 8; Binswanger and Sillers, 1983), shifting household labor away from farming enterprises (Rosenzweig and Stark, 1989; Rose, 2001), and shifting from productive to non-productive but more liquid assets as precautionary savings (Paxon, 1992; Zimmerman and Carter, 2003; Fafchamps, 2003). While ex-post climate impacts are episodic and associated with adverse climatic extremes; ex-ante responses to climate variability impact the poor even in years when climate conditions are favorable. Empirical research shows that this impact can be substantial. For households within ICRISAT's village studies in India, Rosenzweig and Binswanger (1993) showed that climatic risk substantially reduces profitability per unit of productive asset, and does so more for poor than for wealthier farmers. A unit standard deviation increase in climatic variability reduced mean farm profits by 15% for farmers at the median wealth class, and by 35% for farmers in the lower quartile of wealth, indicating that less wealthy farmers were more willing than their relatively wealthy neighbors to sacrifice income to buffer themselves against climate variability. Zimmerman and Carter (2003) estimated that relatively poor farmers in six villages in Burkina Faso forego about 18% of their income to buffer against the existing level of risk (attributed primarily to climate variability), primarily by maintaining precautionary stores of grain, while the relatively wealthy farmers in the sample forego only 0.4% of income. For communal farm households in Zimbabwe, Elbers et al. (2003) attributed about a 30% reduction of wealth accumulation at the end at the end of a 50-year simulation to ex-ante responses to uncertainty, primarily associated with climate.

2.4. Climate variability and the persistence of poverty

Climatic and other external shocks, and sometimes deliberate choices to forgo current consumption to invest in one's future, can push people into a period of temporary poverty. While transient poverty can involve substantial hardship, poverty is of particular concern from a development perspective when it is chronic rather than transitory. A *poverty trap* implies the existence of some threshold level of assets, below which individuals are unable to accumulate the necessary resources to escape poverty without external intervention. Poverty traps result from the interplay between household asset stocks, exogenous factors (e.g., markets, technology, information) that influence returns on assets, and stochastic shocks (Barrett, 2004).

Climate variability contributes to poverty traps in several ways. First, climatic uncertainty contributes to reduced average income by prompting conservative, low-risk, low-return asset portfolios and livelihood strategies (the ex ante climate impact). Second, because tolerance to risk tends to decrease with decreasing resource endowment, returns per unit of productive asset also decrease at low levels of assets – a necessary condition to the existence of a poverty trap. The relationship between asset endowment, risk tolerance, returns per unit of asset forces people into distinctly different, defensive livelihood strategies when the level of assets falls below a critical level (Zimmerman and Carter, 2003; Barrett, 2004). Third, by reducing the willingness of poor households to invest resources that might be needed to buffer against future shocks, and the willingness of lenders to supply credit to poor households, climate variability limits access to the capital needed to enter into more profitable enterprises. Fourth, by forcing households to divest productive assets, severe or repeated climate shocks push some below the threshold associated with a poverty trap.

Assistance strategies that focus exclusively on ex post losses are expensive, and have limited effectiveness. The disturbing trend toward reduced spending on rural development over the last decade leaves the poor increasingly vulnerable to climatic and other shocks, which in turn increase the need for external relief expenditures. The increasing demand for disaster relief assistance competes with development for limited international aid funds, resulting in a spiral of increasing poverty, vulnerability and dependency that Barrett and Carter (2001) refer to as the “relief trap.”

3. Predicting Climate Variations

We propose that appropriate use of climate information – historic records to quantify variability at a range of time scales, real-time monitoring of climate and related environmental variables, and prediction at time scales ranging from daily weather to climate change projections – to manage the impacts of climate variability will contribute significantly to a comprehensive strategy to reduce hunger and rural poverty. Prediction at the seasonal time scale holds particular promise because it matches the time scale between strategic climate-sensitive pre-planting decisions and harvest of staple foods, and the lead-time required to mobilize and distribute food aid when climatic shocks to local food production necessitate external assistance. Climate variability has received less attention than other development issues, in part because it has been considered part of the environmental baseline that is not amenable to intervention. Fortunately, climate conditions in the months ahead no longer need to be accepted as a total unknown. Improvements in our understanding of interactions between the atmosphere and its underlying sea and land surfaces, advances in modeling the global climate system, and substantial investment in monitoring the tropical oceans now provide a degree of predictability of climate fluctuations at a seasonal lead time in many parts of the world.[2]

3.1. Basis for seasonal climate prediction

The atmosphere has a short memory. The current state of the atmosphere will exert sufficient influence to allow prediction only about 5-10 days into the future – the time scale of short- and medium-range weather forecasts. Yet prediction at the seasonal (i.e., $ 3 months) time scale, far beyond the predictability limit for the atmosphere alone, is possible primarily because the atmosphere responds to the more slowly varying ocean and land surfaces (Charney and Shukla, 1981). These slowly evolving surface boundary conditions exert an influence on the tropical atmosphere by redistributing the surface heating, and thus, the low-level wind fields, tropical convection and subsequent atmospheric heating that drives the global atmospheric circulation. The persistence of temperatures of the upper ocean and characteristics of land surfaces provide a degree of predictability out to a few months (Frankignoul, 1985).

Sea surface temperatures (SSTs) over the tropical Pacific Ocean show some persistence up to about six months. The El Niño-Southern Oscillation, or ENSO, refers to shifts in SSTs in the eastern equatorial Pacific (El Niño in warm years, La Niña in cool years) and coupled atmospheric circulation patterns in the tropical Pacific (the Southern Oscillation). Globally, ENSO is the most prominent source of climate variability at seasonal to interannual time scales. Models of the global climate system that couple the upper ocean or land surface to the atmosphere and allow them to evolve potentially permit predictability at even longer time scales (Rosati et al., 1997; Zeng et al., 1999). Land surface characteristics also vary at time scales considerably longer than those of the atmosphere, and therefore potentially provide additional extended predictability (Fennessey and Shukla, 1999, and references therein; Douville and Chauvin, 2000).

3.2. Methods for seasonal climate prediction

Prediction methods of the IRI and most other operational seasonal forecast centers are based on numerical general circulation models (GCMs) that represent the physical processes and dynamic interactions in space of the global climate system. Two types of numerical models are currently used for climate prediction. Atmospheric general circulation models (AGCMs) are used in a "two-tiered" climate prediction approach in which the SST boundary conditions are predicted first, and are then used to force the overlying atmosphere (Hunt, 1997; Bengtsson et al., 1993). In coupled general circulation models (CGCMs), both the atmosphere and the boundary conditions are allowed to evolve freely and influence each other. Because the SST fields in the current generation of CGCMs tend to drift away from realistic values as the simulation proceeds, resulting in unrealistic atmospheric responses, AGCMs are still more commonly used than CGCMs for operational seasonal climate forecasting (Hunt, 1997; Mason et al., 1999). However, CGCMs are often used to predict SST fields in two-tiered forecasting systems, and are beginning to emerge in the arena of operational climate forecasting (Stockdale et al., 1998).

---

[2] A review by Goddard et al. (2001) provides a useful introduction to seasonal climate prediction.

Several methods are used to improve the predictions of numerical climate models. GCM predictions are based on ensembles of model runs that differ in their boundary conditions, initial atmospheric conditions, or parameterization (Sivillo et al., 1997). An ensemble approach lends itself to probabilistic forecasts, and allows separation of the components of variability due to boundary layer forcing and due to the chaotic nature of the atmosphere. Even the best GCMs contain systematic errors, such as shifts in the location of spatial rainfall patterns, thus reducing the apparent prediction skill of the GCM. Because each model has different errors associated with differing assumptions and representations of sub-grid scale processes, combining the predictions from several models improves the predictions by canceling out some of these errors (e.g. Barnston et al. 2003; Robertson et al. 2000).

Statistical transformations can often improve prediction skill by correcting for systematic shifts in the location of spatial rainfall patterns that result from the influence of local factors that the coarse resolution of GCMs cannot capture, such as mountains, vegetation contrasts and land-water contrasts. Furthermore, since the large-scale features that the GCM can predict affect local seasonal climate variations, statistical transformations can incorporate this information to improve prediction. Statistical downscaling increases the spatial resolution of forecasts by applying statistical transformations to climate data observed at a higher resolution than the GCM grid cells. An alternative approach to enhance the resolution of GCM forecasts is to run a high-resolution climate model over a limited geographic region, using the large-scale circulation output from a GCM as the input to the regional climate model. The combined procedure is commonly known as *dynamic downscaling*.

Statistical models also provide useful information in some regions where the dynamical models have weak skill (e.g., Hastenrath, 1995). With the development of global observing networks that measure air temperature, sea temperature, precipitation, and some aspects of the atmospheric circulation, statistical prediction methods have evolved considerably through the 20th century. In most cases, statistical forecasts of seasonal climate anomalies depend heavily upon the SST boundary forcing, which is also the fundamental source of predictability in two-tiered dynamical modeling approaches. Most predictability is associated with the tropical Pacific. The skill of seasonal climate forecasts is often reduced in neutral ENSO years (Landman and Mason, 1999; Goddard and Dilley, 2004). Although some improvements in skill have been claimed when atmospheric predictors are included (e.g., Hastenrath et al., 1995), in most cases, these predictors reflect atmospheric responses to ENSO, and therefore do not imply that the atmosphere has sufficient memory to provide predictability at seasonal time scales.

3.3. Geographic distribution of seasonal predictability

Predictability of rainfall at a seasonal time scale varies substantially with location and time of year. The highest predictability with available models is found in Northeast Brazil, and a region encompassing most of Indonesia and the southern Philippines. Climate models show potentially useful forecast skill over several other regions throughout the tropics and sub-tropics. In Africa, regions of moderately high to modest predictability (Fig. 1) overlap with the African “hunger hotspots” that the Millennium Project Hunger Task Force has targeted (Balk et al., 2004). A region of high predictability, centered around Lake Victoria, encompasses hotspots in southern and western

Kenya and northern Tanzania. Moderate prediction skill extends into southern Ethiopia. Predictability in East Africa is stronger for the October-December short rains than for the March-May long rains. Rainfall over West Africa shows good predictability in the humid coastal region along the Gulf of Guinea (including hotspots in Ghana and part of Nigeria). Prediction skill with current models decreases to moderate levels northward into the hotspots in the Sahel (Mali, Burkina Faso and Niger). Much of southern Africa shows moderate predictability at a seasonal time scale. Recent work, for example, statistical transformations of AGCM forecasts over eastern Africa, and CGCM forecasts in southern Africa, appear to increase prediction skill significantly beyond what is available directly from AGCM forecasts.

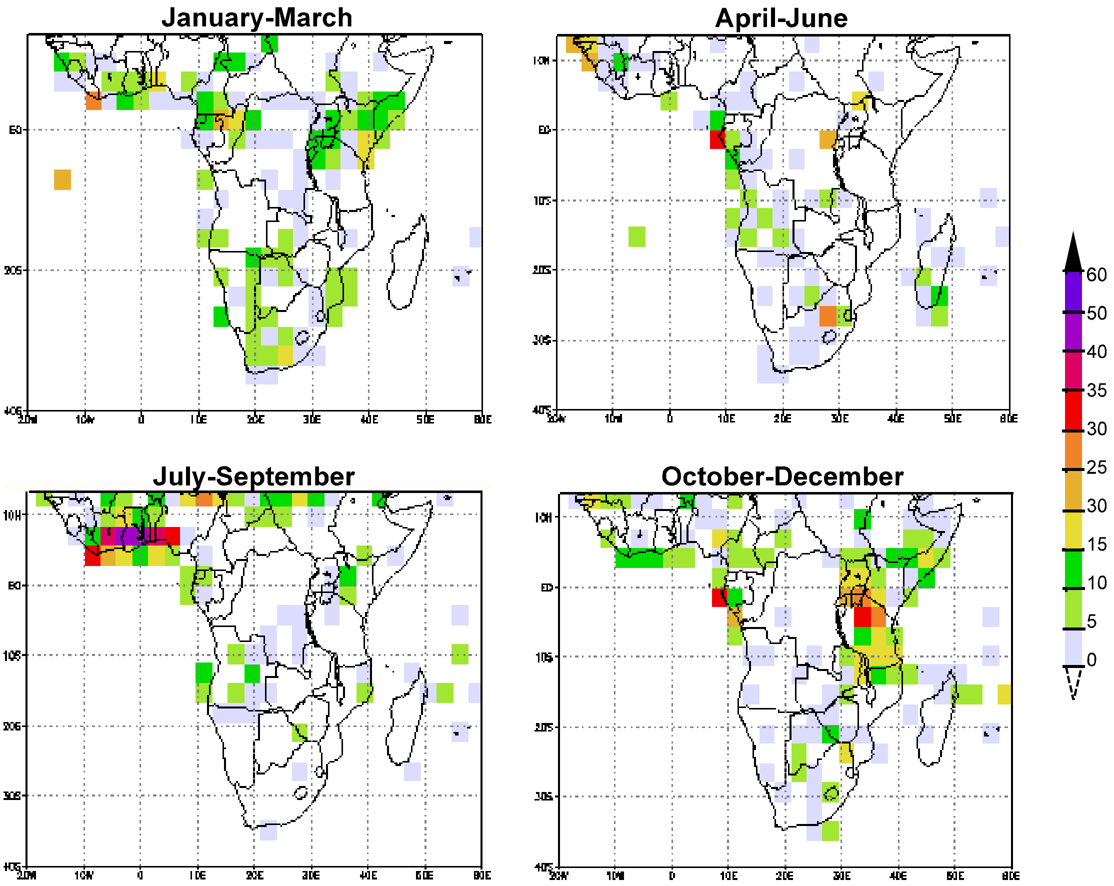

Figure 1. Skill metric (ranked probability skill score) of probabilistic 3-category forecasts of seasonal total rainfall. The forecasts (1950-1995) are based on a multi-model superensemble using 3 atmospheric general circulation models. Values greater than 0 indicate that this forecast approach outperforms a reference forecast of climatology. Values greater than 5 are highly statistically significant.

3.4. Future prospects for improving seasonal prediction

Several areas of active research are likely to yield improvements in the skill of seasonal forecasts in the near future. First, improvements in forecasting SSTs, using both statistical and dynamic models, will come largely through improved understanding and from improved observational networks in the tropical ocean basins. Second, improved initialization techniques and coupling strategies that reduce initialization problems and model drift will improve coupled ocean-atmosphere prediction systems. Third, improvements in computer speed and capacity will allow GCMs to be run at higher spatial resolutions. Higher resolution is needed to resolve terrain and features that the current generation of GCMs, with effective horizontal resolutions of 100-200 km, cannot resolve. Fourth, the influence of land surfaces on climate will be exploited through better initialization of land surface characteristics, and better representation of land-atmosphere interactions through improved parameterization of those sub-grid scale processes. Soil moisture, in particular, is important for surface energy and moisture budgets, and hence for temperature and precipitation forecasts.

Seasonal climate forecasts are inherently probabilistic, and will always have some uncertainty. The skill level necessary for a forecast to be useful depends on the application and the requirements of the decision maker. In many cases, to be useful for decision-making climate information must be tailored for the decision options available. This involves identifying which aspects of climate affect the outcome of interest, how well those factors can be monitored and predicted and which other (non-climatic) factors must be taken into account by the decision maker. Decisions that incorporate climate information and forecasts are generally not based solely on these factors, and the value of climate information for improving decision-making can only be evaluated in the context of an overall decision-support information package and, over time, in terms of the degree of improvement in the outcomes themselves.

4. Managing Climate Risk

The key elements of a strategy for managing climate risk to enhance food security and rural livelihoods are:

- Enhancing early warning systems to support appropriate assistance;
- Fostering appropriate use of climate information to manage risk in agriculture and livelihoods at a range of levels, including: vulnerable farming populations, intermediary institutions that directly influence farm decision making, and institutions that make decisions at a large scale that influence food security.

Because these interventions necessarily involve the coordinated actions of a range of stakeholders operating at a range of scales, we add a third element:

- Strengthening institutional capacity and coordination to support generation, communication and application of appropriate climate information.

4.1. Enhance early warning systems

The ability to anticipate climate shocks and associated losses through monitoring and forecasting creates an opportunity for governments, NGOs, international aid organizations and donors to provide targeted, temporary assistance to replace lost food income, and maintain households at at least minimally food secure levels. This intervention stabilizes consumption, reducing immediate hardship and alleviating the need for households to liquidate productive assets. With this safety net in place, households and communities can begin to achieve economic security, reducing vulnerability to future shocks.

Box 1. Greater Horn of Africa Food Security Outlook Forum

In August 2004, experts and stakeholders concerned with food security early warning and response convened in Nairobi for the first regional food security outlook forum. The experts examined the current food security situation within the region; the climate outlook for September through December 2004; and likely climate effects on crops, livestock, diseases, and pests over the season. The effects of the projected behavior of these variables – based on the climate outlook – were interpreted as food security impacts for the various livelihood zones within the region. This allowed the forum participants to make informed judgments about the potential trajectory of currently food insecure hotspots through the coming season.

The Food Security Outlook Forum, associated with the Greater Horn of Africa Climate Outlook Forum, was a first attempt to systematically incorporate climate forecast information into a regional food security analysis, and the results should be considered experimental at this stage. As confidence in the outlooks grows, the intent is that they can be used to anticipate and avert food-related crises, identifying specific, climate-related risk factors. This information can be used by assistance agencies and ultimately perhaps by affected people to manage food security risks, as opposed to reacting to food security emergencies. Accomplishing this objective will require strengthening linkages between food security analyses and responses, incorporating such measures as response triggers and contingency response funds.

Effective use of scarce relief resources requires knowing who is food-insecure, where, when and why. This information can be used to further distinguish between the chronically hungry and food insecure versus those who are episodically hungry and food insecure, or barely food secure. For the chronically hungry, an assessment of constraints to enhanced livelihoods is needed in order to devise strategies to increase livelihood options or subsidize consumption until food security is achieved. Mapping household livelihood strategies and assessing climate-related risks for the different livelihood strategies can inform targeted assistance to those who are episodically food insecure. Several national and regional early warning systems provide information to aid organizations about emerging food security crises. Advances in environmental monitoring and prediction have the potential to improve the lead-time, accuracy and geographic specificity of such early warning systems. For example, the IRI and others have developed methods that increase lead-time and accuracy of geo-referenced crop yield and NDVI- (normalized difference vegetation index) based forage forecasts by incorporating seasonal climate forecasts (e.g., Hansen et al., In press). Integrating probabilistic forecasts of food production into models of household vulnerability have the potential to improve aid assessments and targeting at a relatively long lead-time. A recently-initiated food security outlook forum, associated with the East Africa Climate Outlook Forum, provides a mechanism for engaging experts and stakeholders concerned with food security early warning and response (Box 1).

4.2. Foster climate risk management in agriculture at multiple levels

Developing flexible, proactive approaches to managing climate variability within vulnerable rural communities and among a range of institutions operating at community, sub-national, and national levels is a crucial part of a strategy for reducing the number of food-insecure by half by 2015. Agriculture is a complex, hierarchical system with many decision makers ranging from individual farmers to agribusiness to natural resource managers to government policy makers, managing systems whose spatial scales range from fields to nations or regions. In the context of a strategy to reduce hunger through adaptive climate risk management, we highlight the farmer, a set of intermediary institutions who interact with farmers and directly influence farm decision making, and institutions that make climate-sensitive decisions at a large scale that influence food security.

4.2.1. Farm-level risk management

Farmers and farm laborers are both the suppliers of staple foods through markets, and the largest group of food-insecure. Farmers routinely make critical climate-sensitive agricultural and livelihood decisions months before the impacts of climate are realized. They are also the ultimate managers of natural resources over much of the landscape in poorer countries. In general, the link between climate variability and access to food is more direct, and the opportunities for climate-related interventions are greater, for farmers and than for other groups of food insecure. Where the necessary conditions are in place, or can be put into place, the ability to anticipate climate fluctuations provides opportunity for adaptive management, both to prepare for expected adverse conditions, and to increase production and income during favorable conditions. Potential applications include: selection of livelihood activities, crops and cultivars; allocation of land and household labor; soil, water, crop, livestock and forage management; securing credit and production inputs; leasing of land; maintenance of homes, equipment, roads, grain storage and soil conservation structures; and marketing, savings and investing strategies.

The requirements for applying climate information successfully are much the same as for other agricultural technologies, and include: fit with farmers' goals and constraints, appropriate information and technical guidance underpinned by sound research, access to appropriate production inputs and the capital required to purchase them, efficient markets for surplus production, time for learning and adaptation, and institutions and policies that foster these conditions. The need for timely information, the challenges of using explicitly probabilistic information and the range of livelihood decisions that could be involved set climate applications apart from many other agricultural technologies. Policy and institutional interventions must play a key role, as Ellis (Ellis and Freeman 2002; Ellis and Allison 2004) and others (Mjelde et al., 1996; Barrett, 1998; Hansen, 2002) argue. Too often, local institutions and policies inhibit the ability of the poor to obtain cash, gain access to inputs needed for more sustainable agricultural production, and make claims upon authorities for policy reform. The factors that generally impede advances in agricultural development, food security and rural prosperity can also restrict the range of opportunities to benefit from climate information (Walker, 1991). Many of these are targets of the Millennium Project Hunger Task Force.

4.2.2. Intermediary institutions

An effective strategy for empower farming communities to manage climatic risk must involve intermediary institutions that support three areas of intervention:

- Providing relevant, timely climate information to rural populations;
- Fostering and guiding adaptive management responses to climate variations;
- Addressing resource constraints to adaptive responses.

Communication of climate information to rural populations can potentially involve a range of institutions, including meteorological services, agricultural extension services, other government agencies or NGOs, farmers' associations and the commercial media. Experience shows that climate information is most useful when it comes through existing, trusted sources of agricultural information and advice, and involves group interaction among farmers and with technical experts. The media, and particularly radio in much of rural Africa, may play an essential role in disseminating climate information, but requires safeguards to ensure the quality and relevance of the information. Investment in information technology and rural communication infrastructure is expected to open new opportunities for disseminating climate information dissemination to rural communities.

Local and national agricultural institutions responsible for technical advice, research support and advocacy should be involved in identifying information needs and providing feedback to forecast providers. If farmers are to apply seasonal climate forecasts to improve crop management, they must be able to interpret the information at a local scale, translate forecasts into production and economic outcomes associated with alternative management strategies, and clearly understand forecast uncertainty with respect to those outcomes. Attention to these requirements will enhance to the relevance of climate information products. Where appropriate, climate information should be integrated with market and other relevant information, and with technical advice.

We expect that technical guidance based on sound research will enhance use and benefits of climate information. This is a traditional mandate of NARES, but research teams in pilot-scale projects, and sometimes NGOs play that role. Although smallholder farmers invariably have ideas about how they could respond to advance climate information, they consistently express the need for access to technical experts who can discuss ideas and guide appropriate management response to forecasts. Research is also needed to identify populations, farming systems and management responses poised to benefit; design appropriate information products; identify and guide market and policy interventions to address constraints to adaptive management; and evaluate impacts.

Public and private sector institutions that influence the availability of production inputs are in a position to reduce resource constraints to desirable farm-level responses to forecasts. For example, access to seeds for cultivars appropriate to predicted rainfall often limits the flexibility of farmers to respond, but if seed distribution centers are also using forecasts, arrangements for accessing these seeds can be found. Opportunity for increased profit in climatically favorable years may motivate private sector suppliers of seed and other production inputs to increase flexibility to respond to changing demand associated with climate forecasts. In cases where rural credit markets exist but exclude poorer rainfed farmers due to risk and perhaps history of defaults, creative financing options tied to climate information may make credit more available to these farmers (section 5.3). Some developing countries, such as India, exert considerable influence over the supply of production inputs and credit, and are in a position to coordinate the distribution of inputs with anticipated climatic conditions as part of a national strategy for enhancing food security. In particular contexts, managers of irrigation systems may use climate-based streamflow forecasts to improve water allocation to ensure irrigation water availability, or to warn farmers earlier when water is expected to be unavailable.

4.2.3. Large-scale market and resource management

In addition to the direct impacts on food production, several secondary impacts of climate shocks can significantly impact access to food. Examples include price responses to changes in production, changes in value of buffer assets such as livestock, and damage to transportation infrastructure. In Ethiopia and West Africa, impacts of severe drought extended throughout the rural economy, causing loss of income to purchase food even for those working outside of the farm sector (Sen, 1981; Czukas et al., 1998). While a range of institutions can act as intermediaries and facilitators of individual decision making, institutions at a range of levels also make climate-sensitive decisions at a larger scale that have an indirect impact on food security. As a complement to local-level decision-making by the population at risk, a strategy for managing climate risk must consider the range of more centralized, larger scale options for using climate information to prevent or dampen secondary climate-related shocks that affect food security. In particular contexts, these may include management of imports and national grain reserves to stabilize prices, preemptive borrowing for balance of payments support, adjustments in water allocation from multipurpose reservoirs to ensure irrigation water availability or intervene when water shortfalls are expected, and rural road maintenance to ensure access to markets. These types of decisions are generally at a relatively large spatial scale; are made by intermediaries at a professional, managerial or political level; and require a different type of analysis, information and communication procedures than in the case of risk management directly by the population at risk.

One potential application with strong implications for food security is the use of climate information to manage markets for staple foods to stabilize prices. Where markets are closed or inefficient, climate-induced variations of aggregate production can result in large fluctuations in prices that can negate production benefits of favorable climatic conditions in good years, and cause hardship to poor consumers in poor climatic years. Although experience with using climate information to intervene in markets is still limited, economy-wide modeling in Mozambique suggests considerable potential aggregate benefits of market applications of climate forecasts (Arndt and Bacou, 2000; Arndt et al., 2003). Other interventions, such as investment in transportation infrastructure and liberalizing intra-regional trade policy, can substantially reduce the sensitivity of market prices to climate variability.

4.3. Strengthen institutional capacity and coordination

A strategy of maintaining and strengthening global and national climate observing systems; and strengthening partnerships, at all levels, between institutions working on climate-sensitive development problems and providers of climate information, will provide the necessary foundation for climate-related interventions across several of the MDGs. Ocean monitoring systems, such as then TOGA-TAO array in the tropical Pacific, are essential for forecasting beyond two weeks. They should be sustained and replicated in the other tropical ocean basins. Similarly, national meteorological observing systems are the foundation for understanding climate variability and for locally relevant prediction. In many countries in Africa, there is a need to increase the density of observing stations, particularly for rainfall, in regions with high risk of food insecurity or under-exploited opportunity. Valuable historic records often need to be compiled, documented, digitized and made more accessible.

Addressing climate-related constraints to food and livelihood security requires strengthening coordination between climate, agricultural development, market and food aid institutions at a range of scales. Agricultural and meteorological institutions are typically separated at the highest levels of national government, and even within the United Nations. This sometimes results in competition and redundancy when, for example, NARES maintain meteorological observing networks and produce their own forecasts, and meteorological services issue agricultural recommendations. Countries should seek to bridge this gap in a manner that ensures that meteorological services serve development needs. National meteorological services with limited resources should partner with regional and international climate institutions to enhance their access to global climate and predictive models.

A comprehensive strategy requires balanced and coordinated attention to safety nets (relief interventions to protect vulnerable populations from persistent impacts of shocks, i.e., from entering poverty traps), and what Barrett (2004) termed “cargo nets” – development interventions to help lift poor out of poverty traps toward asset accumulation and reduced vulnerability to shocks. In the context of climate variability, safety nets protect vulnerable populations during periods of adverse conditions, while cargo nets assist the poor to increase investment to take advantage of favorable conditions, with the potential to invest the returns in productive assets for the future. The ability to anticipate adverse and favorable climatic conditions early enough can aid in mobilizing and targeting both types of intervention. This calls for efforts to bridge the historic gap between emergency relief and agricultural development institutions.

5. Synergies

Persistent societal problems are persistent because they result from multiple factors, and therefore don't respond to single solutions; this is certainly true for food insecurity. The Millennium Project Hunger Task Force has proposed a multi-pronged strategy for combating hunger. The proposed strategy for managing climate variability has appealing synergies with other interventions that target hunger if the efforts are sufficiently integrated. Seasonal forecasts and related climate interventions hold promise for addressing a significant constraint to other development efforts targeting food and rural livelihood security, and therefore have the potential to add value to those development efforts. On the other hand, the challenges that farmers face in applying advance climate information to their production and livelihood decisions are often the same challenges that generally constrain development. Ongoing development efforts, and those proposed within the Millennium Development Goal strategy, are targeting these constraints, and therefore add value to the investment in climate monitoring, prediction and application.

5.1. Soil fertility management

Soil nutrient depletion is increasingly recognized as the root cause of declining per-capita food production and hence a critical constraint to food security in sub-Saharan Africa (Stoorvogel and Smaling, 1990; Sanchez et al., 1997; Sanchez, 2002). Climatic variability, with its resulting risk of financial loss in poor years, is often cited as one of several reasons for under-investment in soil fertility inputs in rainfed production systems in Africa (e.g., McCown et al., 1991; Vlek et al., 1997; Snapp et al., 2003). Some empirical evidence supports this belief (Moscardi and de Janvry, 1977; Bliss and Stern, 1982, Ch. 8; Binswanger and Sillers, 1983). Efficient use of scarce and varying water supply is possible only if supply of soil nutrients is coordinated with water availability. Many studies (reviewed by Viets, 1962; Rhoads, 1984; Davis, 1994) have shown positive interactions between soil fertility and water use. According to C. T. de Wit (1992), resource use efficiency by crops is highest when all resources are supplied at optimal levels. Available water is not used efficiently when nutrient availability is inadequate. Likewise, nutrients are not used efficiently when water availability is inadequate. As a result, the profitability of fertilizer use and optimal application rates for rainfed agriculture vary considerably from year to year as a function of rainfall (Piha, 1993; Thornton and MacRobert, 1994; Jones et al., 2000; Dimes et al., 2003). The ability to anticipate rainfall before or early in the growing season reduces one of the barriers to investing in fertilizers, and presents opportunity for increasing the efficiency of both water and nutrients through adaptive fertilizer management.

5.2. Small-scale water management

Retaining and using variable rainfall efficiently is a key challenge to food security in regions dependent on rainfed agriculture. As the previous section discusses, adaptive management that matches crop characteristics, production activities and input use to rainfall variations is one way to enhance efficiency of water use. A range of field-, farm- and community-scale water harvesting and water conservation management strategies show promise in particular contexts (Hillel, 2004). The yield benefits and profitability of on-farm water harvesting and conservation strategies that are within the reach of many poorer farmers depend on season rainfall characteristics (Stephens and Hess, 1999; Friesen, 2002; Walker and Tsubo, 2003). In Kenya, tied ridges increased yields on average, but are economically viable only in seasons with moderately low rainfall, as yield increases do not cover the added setup costs when rainfall is either very high or very low (Friesen, 2002). Simulation analyses at another location in Kenya support this conclusion (Stephens and Hess, 1999). Gowing et al. (2003) showed that larger-scale water harvesting could reduce susceptibility to drought years, but also increase the risk of serious erosion in high rainfall years in semi-arid Tanzania. Small-scale water management can therefore benefit from both historic and predictive climate information, and complement the use of climate information for adaptive crop management.

5.3. Markets

Synergies exist between climate risk management and efforts to develop agricultural commodity, input and rural finance markets in Africa. Adoption of agricultural technology, intensification and the production of marketable surpluses depend critically on the profitability of market production. Where commodity markets are closed or inefficient, climate-induced variations of aggregate production lead to large fluctuations in prices that can negate the production benefits of favorable climatic conditions in good years, and cause hardship to poor consumers in poor climatic years. Increased use of climate prediction has the potential to further increase volatility of aggregate production (Phillips et al., 2002). The opportunity to exploit advance climate information to intensify production in average or favorable climatic years depends on access to efficient commodity markets and stable farmgate prices, and therefore can benefit from policies, institutional reforms and investment in transportation infrastructure that improve market integration and efficiency. Governments and private traders may also be able to use climate information to better manage imports, exports and grain storage in a manner that stabilizes prices in the market and at the farm gate. An recent innovative example of the use of climate information within commodity markets is climate-based prediction of Rift Valley Fever to support negotiation of better cattle market terms for pastoralists in East Africa (Box 2).

Box 2. Forecasting Rift Valley Fever.

In the Greater Horn of Africa (GHA), millions of livelihoods in some of the poorest countries, Ethiopia and Somalia for example, depend on livestock. Heavy rains associated with the 1997-98 El Niño lead to major outbreaks of Rift Valley Fever (RVF), a mosquito-borne virus affecting livestock and humans. Fears of the spread of RVF lead livestock importing countries in the Middle East to ban the import of livestock from GHA countries for several years, causing hundreds of millions of dollars in losses to pastoralists in exporting countries. The IRI, Drought Monitoring Center in Nairobi, Inter-African Bureau for Animal Resources, Red Sea Livestock Trade Commission, U.S. Geological Survey and the African Regional Center for the Mapping of Resources for Development have developed a climate-based RVF risk model. The model anticipates climate conditions associated with mosquito breeding. The model has been developed with full support from Chief Veterinary Officers and livestock trade policy-makers in the GHA and Middle East. When operational, it will support animal health and trade decision-making with the intent of minimizing future trade stoppages based on assessment of environmental RVF risks.

The cost and availability of inputs – primarily fertilizers and quality seed – presents a serious challenge to the growth of agricultural production in much of Africa. Economic liberalization and other macroeconomic and policy changes in the 1990s shifted responsibility for input supply from governments to an under-developed private sector (Johnson and Hazell, 2002). Limited access to fertilizers and high quality seed of locally-adapted cultivars can reduce the options farmers have for intensifying production in favorable climatic years. As input market reforms and investment in transportation and fertilizer production infrastructure make fertilizers more available and affordable, the capability to predict climatic conditions that favor strong crop response should contribute to increased average fertilizer use, and hence reduced soil degradation from nutrient mining. Similarly, expanded use of seasonal climate forecasts should increase average demand for certified seeds. Seed suppliers could face both opportunities and significant challenges in responding to year-to-year changes in farmer demand and cultivar preferences due to increased use of seasonal forecasts.

Seasonal climate forecasts already enter into the production, distribution and planning strategies of some seed companies in Africa (Box 3).

Box 3. Climate Prediction and Africa's Seed Industry.

Group	Attributes
Monkey	*"Very quick, active and clever:"* 90-130 day maturity; tolerant to drought, diseases; medium to fast drying rates.
Zebra	*"Hardy animal, graceful to look at, heavy in stature:"* Up to 138-day maturity; good drought tolerance, yield stability.
Lion	*"Fierce:"* moderately long season; high yield potential under rainfed conditions.
Elephant	*"Big, slow in movement:"* Long season, high yielding under intensive management, including irrigation.

SeedCo, a seed producer and supplier based in Zimbabwe and operating throughout southern Africa, use animals to represent the climatic sensitivity of groups of maize cultivars (Table A), and factor seasonal forecasts into their recommendations to farmers. *"A prediction of a good season is likely to result in the farmers purchasing high yielding varieties. A bad season prediction would in turn result in short season varieties demand, increase in small pack requirements, low yield projections, with a strong possibility of possible national government and non-governmental seed aid programs to vulnerable communities in the following season. … Should it be a dry season prediction, earliness is the way to advise. Monkey group and zebra group would be ideal. In wet years, zebra varieties are suitable. … To spread the risk, plant the lion varieties first, followed by the zebra group, with the monkey group suitable for late plantings, early green meallie harvest, and an insurance against hunger."* (*Source:* Malusalila, 2000)

Faida Seeds, Kenya, contracts private farmers throughout Kenya to produce and sells maize and sunflower seed. Most is produced under rainfed conditions. They participate in each Greater Horn Area Climate Outlook Forum; avoid high-risk locations, scale down production, and target drought-tolerant cultivars when the forecast indicates enhanced probability of rain

Rural finance markets (i.e., credit, insurance, savings) can play an important role in buffering against risk, in providing access to inputs for intensified production, and in overcoming barriers to improved sources of livelihood (both farming and non-farm). However, the rural poor who would benefit most often have the least access due to a combination risk of financial loss and poorly-developed rural finance markets. In cases where rural credit markets exist but exclude poorer rainfed farmers due to risk and perhaps history of defaults, creative financing options tied to climate information may make credit more available to these farmers, while providing protection to the lender (Hess, 2003). In particular, seasonal forecasts seem to offer opportunity to improve availability and terms of credit to such farmers by identify the years when likelihood of payoffs to intensified production for the farmer is enhanced, and risk of default to the lender is reduced. Combining forecast-based credit with insurance markets to spread the risk associated with fine-scale variability of rainfall and forecast uncertainty is a promising intervention (Fafchamps, 2003, p. 205; Hess, 2003).

5.4. Extension and communication systems

Farmers' ability to respond adaptively to climate variability requires timely access to information tailored to their needs and scale of decision-making. Equitable access is a major concern when targeting the poor and food-insecure (Archer, 2003). Limited dissemination can bias the value of climate information against the poor, but can be overcome by aggressive, equitable dissemination, as Phillips (2003) demonstrated for communal farm households in Zimbabwe. Adaptive climate risk management, like other agricultural technologies, depends on effective communication and guidance. Although this is the traditional role of agricultural extension services, the need for rapid, widespread dissemination of tailored information and advice places heavy demands on struggling extension services and weak rural communication infrastructure that currently exist in many countries particularly in Africa. Efforts to strengthen extension services and rural communication infrastructure will contribute greatly to the potential for climate information to contribute to food and livelihood security. On the other hand, climate applications may increase the demand for, and effectiveness of, extension programs. In India, about a third of inquiries that a new telephone-based extension program receives relate to climate (R.C.A. Jain, Member Secretary, National Farmer's Commission of India. Presentation at IRI, June 2004). Therefore, climate interventions targeting hunger and rural poverty both depend on, and add value to, investment in agricultural extension systems and rural communication infrastructure.

6. Limitations

Within agriculture, techniques for using historic climate records to characterize production risk, and short-term weather forecasting are well developed. On the other hand, prediction at a seasonal time scale is a relatively new technology. Methodology for applying seasonal climate prediction to agricultural management and early warning is even newer. Although there are strong theoretical arguments for expecting substantial benefits to food and livelihood security, empirical evidence is still limited relative to many other interventions that target hunger. This is due in part to lack of attention to impact evaluation in those regions where forecasts are being widely promoted. Ongoing advances in using seasonal forecasts and environmental monitoring to predict food production can be used with confidence for early warning applications. Concerns about credibility of farm-level application can be addressed through a phased strategy that starts with well-designed pilot studies. Well-designed participatory pilot studies provide opportunity to evaluate acceptance and benefits; build a knowledge base about viable decision responses, information requirements, and constraints; and begin to build capacity within NARES. The geographic distribution of predictability is another limitation. Like other technological interventions, the proposed climate-related interventions depend on political will and wisdom, transportation and communication infrastructure and functioning institutions. They also depend on the existence of long-term climate records in the target regions, although satellite-derived proxies offer some potential to address data limitations.

References

Archer, E.R.M., 2003. Identifying underserved end-user groups in the provision of climate information. *Bulletin of the American Meteorological Society* 84:1525-1532.

Arndt, C., Bacou, M., 2000. Economy wide effects of climate variability and prediction in Mozambique. *American Journal of Agricultural Economics* 82:750-754.

Arndt, C., Bacou, M., Cruz, A., 2003. Climate forecasts in Mozambique: an economic perspective. In: O'Brien, K., Vogel, C. (Eds.), *Coping with Climate Variability: The Use of Seasonal Climate Forecasts in Southern Africa*. Ashgate Publishing, Abingdon, UK. pp. 129-152.

Balk, D., Flor, R., Gaskell, J., Levy, M., Sharma, M., Storeygard, A., 2004. *An Assessment of Hunger Hotspots*. Commissioned paper submitted to the Millennium Project Hunger Task Force.

Barnston, A.G., Mason, S.J., Goddard, L., DeWitt, D.G., Zebiak, S.E., 2003. Multimodel ensembling in seasonal climate forecasting at IRI. *Bulletin of the American Meteorological Society* 84:1783-1796.

Barrett, C.B., 1998. The value of imperfect ENSO forecast information: discussion. *American Journal of Agricultural Economics* 80, 1109-1112.

Barrett, C.B. 2004. Rural poverty dynamics: development policy implications. *Agricultural Economics*, In press.

Barrett, C.B., Carter, M.R., 2001. Can't get ahead for falling behind: development policy, poverty, and relief traps. *Choices*, winter 2001-2002: 35-38.

Benestad, R.E., 2001. A comparison between two empirical downscaling strategies. *International Journal of Climatology* 21:1645-1668.

Binswanger, H., Sillers, D.A. 1983. Technological priorities for farming in Sub-Saharan Africa. *World Bank Research Observer* 3:81-98.

Bengtsson, L., Schlese, U., Roeckner, E., Latif, M., Barnett, T.P., Graham, N.E., 1993. A two tiered approach to long-range climate forecasting. *Science* 261:1026-1029.

Bliss, C.J., Stern, N.H., 1982. *Palanpur, the Economy of an Indian Village*. Clarendon Press, Oxford.

Carter, M.R., 1997. Environment, technology, and the social articulation of risk in West African agriculture. *Economic Development and Cultural Change* 45: 557-590.

Charney, J.G. Shukla, J., 1981. Predictability of monsoons. In: J. Lighthill, R. P. Pearce (Eds.), *Monsoon Dynamics*. Cambridge University Press, New York, pp. 99-109

Czukas, K., Fafchamps, M., Udry, C., 1998. Drought and savings in West Africa: Are livestock a buffer stock? *Journal of Development Economics* 55:273-305.

Davis, J. G. 1994. Managing plant nutrients for optimum water use efficiency and water conservation. *Advances in Agronomy* 53:85-120.

Dercon, S., 1996. Risk, crop choice, and savings: evidence from Tanzania. *Economic Development and Cultural Change* 44:485-513.

Dercon, S., 2002. Income risk, coping strategies, and safety nets. *The World Bank Research Observer* 17(2):141-166.

Dercon, S. 2004. Growth and shocks: evidence from rural Ethiopia. *J. Development Economics* 74:309-329.

de Wit, C. T. 1992. Resource use efficiency in agriculture. *Agricultural Systems* 40:125-151.

Dilley, M. and Boudreau, T.E., 2001. Coming to terms with vulnerability: A critique of the food security definition. *Food Policy* 26:229-24.

Dimes, J., Twomlow, S., Rusike, J., Gerard, B., Tabo, R., Freeman, A., Keatinge, J.D.H., 2003. *Increasing research impacts through low-cost soil fertility management options for Africa's drought-prone areas*. Paper presented at: International Symposium for Sustainable Dry land Agriculture Systems, ICRISAT Sahelian Center, Niamey, 2-5 December 2003.

Douville, H., Chauvin, F., 2000. Relevance of soil moisture for seasonal climate predictions: a preliminary study. *Climate Dynamics* 16:719-736.

Easterly, W., 2001. *The Elusive Quest for Growth*. Cambridge: MIT Press.

Elbers, C., Gunning, J.W., Kinsey, B.H., 2003. *Growth and Risk: Methodology and Micro Evidence*. Tinbergen Institute Discussion Paper No. 2003-068/2. (Available online at http://ssrn.com/abstract=441140).

Ellis, F., Allison, E., 2004. *Livelihood Diversification and Natural Resource Access.* FAO LSP.

Ellis, F., Freeman, H.A., 2002. *Rural Livelihoods and Poverty Reduction Strategies in Four African Countries*. University of East Anglia.

Fafchamps, M., 2003. *Rural Poverty, Risk and Development.* Edward Elgar Publishing, Glos, UK.

Fennessey, M.J., Shukla, J., 1999. Impact of initial soil wetness on seasonal atmospheric prediction. *Journal of Climate* 12:3167-3180.

Frankignoul, C., 1985. Sea surface temperature anomalies, planetary waves and air-sea feedback in the middle latitudes. *Review of Geophysics* 23:357-390.

Friesen, D., *Rain Traps Make More Maize*. IFDC Report, December 2002. (Available online at http://www.ifdc.org/PDF_Files/December_2002E_News.pdf).

Goddard, L., Dilley, M., 2004. El Niño: Catastrophe or opportunity? *Journal of Climate*, in press.

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

Gowing, J.W., Young, M.D.B., Hatibu, N., Mahoo, H.F., Rwehumbiza, F., Mzirai, O.B., 2003. Developing improved dryland cropping systems for maize in semi-arid Tanzania. Part II. Use of a model to extrapolate and add value to experimental results. *Experimental Agriculture* 39:293-306.

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

Hansen, J.W., Potgieter, A., and Tippett, M., 2004. Using a general circulation model to forecast regional wheat yields in Northeast Australia. *Agricultural and Forest Meteorology*, in press.

Hastenrath, S., 1995. Recent advances in tropical climate prediction. *Journal of Climate* 8:1519-1532.

Hess, U., 2003. *Innovative financial services for rural India: monsoon-indexed lending and insurance for smallholders*. Agriculture & Rural Development Working Paper 9. The World Bank, Washington, DC.

Hillel, D., 2004. *Efficient and Sustainable Water Management in Small Scale Farming*. Commissioned paper submitted to the Millennium Project Hunger Task Force.

Hunt, B.G., 1997. Prospects and problems for multi-seasonal predictions: some issues arising from a study of 1992. *International Journal of Climatology* 17:134-154.

Johnson, M., Hazell, P., 2002. *Cutting Hunger in Africa Through Smallholder-led Agricultural Growth*. Presented at Johannesburg 2002 - World Summit on Sustainable Development (WSSD). IFPRI, Washington, DC. (Available online at http://www.ifpri.org/themes/ieha/iehatech.pdf).

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

Kebede, Y., 1992. Risk behavior and new agricultural technologies: the case of producers in the central highlands of Ethiopia. *Quarterly Journal of International Agriculture* 31:269-284.

Landman, W.A., Mason, S.J., 1999. Operational prediction of South African rainfall using canonical correlation analysis. *International Journal of Climatology* 19:1073-1090.

Malusalila, P.M. 2000. Experiences of an agricultural input supplier. In: *Proceedings of the International Forum on Climate Prediction, Agriculture and Development*. IRI-CW/00/1. International Research Institute for Climate Prediction, Palisades, New York, pp. 82-86.

Marra, M., Pannell, D.J., Abadi Ghadim, A., 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems* 75:215-234.

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

McCown, R.L., Wafula, B.M., Mohammed, L., Ryan, J.G., Hargreaves, J.N.G., 1991. Assessing the value of a seasonal rainfall predictor to agronomic decisions: the case of response farming in Kenya. In: Muchow, R.C., Bellamy, J.A. (Eds.), *Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Sub-tropics.* CAB International, Wallingford, UK, pp. 383-409.

Mjelde, J.W., Thompson, T.N., Nixon, C.J., 1996. Government institutional effects on the value of seasonal climate forecasts. *American Journal of Agricultural Economics* 78:175-188.

Moscardi, E., and A. de Janvry., 1977. Attitudes toward risk among peasants: An econometric approach. *American Journal of Agricultural Economics.* 59:710– 716.

Morduch, J., 1990. *Risk, Production and Paving: Theory and Evidence from Indian Households.* Harvard Univ., Dept. of Economics, Cambridge, Mass.

Paxon, C., 1992. Using weather variability to estimate the response of savings to transitory income in Thailand. *American Economic Review* 82:15-33.

Phillips, J., 2003. Determinants of forecast use among communal farmers in Zimbabwe. In: O'Brien, K., Vogel, C. (Eds.), *Coping with Climate Variability: The Use of Seasonal Climate Forecasts in Southern Africa*. Ashgate Publishing, Abingdon, UK. pp. 110-126.

Phillips, J.G., Deane, D., Unganai, L., Mutikani, V., 2002. Implications of farm-level response to seasonal climate forecasts for aggregate grain production in Zimbabwe. *Agricultural Systems* 74:351-369.

Piha, M.I., 1993. Optimizing fertilizer use and practical rainfall capture in a semi-arid environment with variable rainfall. *Experimental Agriculture* 29:405-415.

Rhoads, F.M., 1984. Nitrogen or water stress: Their interrelationships. In: R. D. Hauck (Ed.) *Nitrogen in Crop Production*. ASA-CSSA-SSSA, Madison, Wis., pp. 307-317.

Robertson, A.W., Zebiak, S., Lall, U., Goddard, L., 2004. Optimal combination of multiple atmospheric GCM ensembles for seasonal prediction. *Monthly Weather Review,* in press.

Rosati, A., Miyakoda, K., Gudgel, R., 1997. The impact of ocean initial conditions on ENSO forecasting with a coupled model. *Monthly Weather Review* 125:754-772.

Rose, E., 2001. Ex ante and ex post labor supply response to risk in a low-income area. J*ournal of Development Economics* 64:371-388.

Rosenzweig, M.R., Binswanger, H.P., 1993. Wealth, weather risk and the composition and profitability of agricultural investments. *The Economic Journal* 103(416):56-78.

Rosenzweig, M.R., Stark, O., 1989. Consumption smoothing, migration and marriage. *Journal of Political Economy* 97:905-926.

Sanchez, P., 2002. Soil fertility and hunger in Africa. Science 295:2019-2020.

Sanchez, P., Izac, A.M., Buresh, R., Shepherd, K., Soule, M., Mokwunye, U., Palm, C., Woomer, P., Nderitu, C., 1997. Soil fertility replenishment in Africa as an investment in natural resource capital. In: Buresh, R., Sanchez, P. (Eds.), *Replenishing Soil Fertility in Africa*. SSSA Special Publication No. 51. Soil Science Society of America, Madison, Wis., USA, pp. 1-46.

Sen, A., 1981. *Poverty and Famines: An Essay on Entitlement and Deprivation.* Clarendon Press, Oxford.

Sivillo, J.K., Ahlquist, J.E., Toth, Z., 1997. An ensemble forecasting primer. *Weather Forecasting* 12:809-818.

Snapp, S.S., Blanke, M.J., Donovan, C., 2003. Realigning research and extension to focus on farmers' constraints and opportunities. *Food Policy* 28:349-363.

Stephens, W., Hess, T.M., 1999. Modelling the benefits of soil water conservation using the PARCH model – a case study from a semi-arid region of Kenya. *Journal of Arid Environments* 41:335-344.

Stockdale, T.N., Anderson, D.L.T., Alves, J.O.S., Balmaseda, M.A., 1998. Global seasonal rainfall forecasts using a coupled ocean-atmosphere model. *Nature* 392:370-373.

Stoorvogel, J.J., Smaling, E.M.A., 1990. *Assessment of Soil Nutrient Depletion in sub-Saharan Africa, 1983-2000*. Report 28, Winand Staring Center for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, Netherlands, 125 pp.

Thornton, P.K., MacRobert, J.F., 1994. The value of information concerning near-ptimal nitrogen fertilizer scheduling. *Agricultural Systems* 45:315-330.

Viets, F.G., Jr., 1962. Fertilizers and the efficient use of water. *Advances in Agronomy* 14:223-264.

Vlek, P.L.G., Kühne, R.F., Denich, M., 1997. Nutrient resources for crop production in the tropics. *Philanthropic Transactions of the Royal Society of London B* 352:975-985.

Walker, S., Tsubo, M., 2003. Crop models as tools to simulate in-field water harvesting under different SOI scenarios. Presented at: *Workshop on Insights and Tools for Adaptation: Learning from Climate Variability*, Washington DC, 18-21 November 2003. (Available online at www.climateadaptation.net/docs/papers/WalkerModelSOI.pdf)

Walker, T.S., 1991. Improved technology in relation to other options for dealing with climatir risk to crop production in the semiarid tropics. In: Muchow, R., Bellamy, J.A. (Eds.), *Climatic Risk in Crop Production: Models and Management for the Semiarid Tropics and Subtropics.* CAB International, Wallingford, UK. pp. 511-525

Walker, T.S., Ryan, J.G., 1990. *Village and Household Economies in India's Semiarid Tropics*. Johns Hopkins University Press, Baltimore.

Zimmerman, F.J., Carter, M.R., 2003. Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints. *Journal of Development Economics* 71:233-260.