Florida's Agriculture and Climatic Variability: Reducing Vulnerability

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A remarkable scientific breakthrough has important financial implications for Florida's agriculture. Meteorologists can now forecast El Niño and its opposite, La Niña, months in advance by monitoring the Pacific Ocean west of Peru. The tropical Pacific atmospheric-oceanic phenomenon known as ENSO (El Niño-Southern Oscillation) is a variation between normal conditions and two extreme states associated with warm or cold sea surface temperatures in the eastern tropical Pacific. ENSO has profound effects on global atmospheric circulation, resulting in regional shifts of temperature and precipitation on a seasonal to interannual time scale (Trenberth 1997). In Florida the most recent El Niño event two years ago created property losses of $500 million and spawned tornadoes that led to more than 100 deaths (Changnon 2000).

Agricultural use of climate information, such as forecasts, has dramatically increased in the last 20 years (Changnon 1999; Stern and Easterling 1999). The emergence of useful climate forecasts means farmers can now know months in advance if a drought or

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excessive seasonal rain is anticipated. Although uncertainty about daily weather remains, knowing which climatic patterns are likely allows decision makers to reduce risks associated with such patterns.[1] Climate forecasts have already proved useful to Florida's forestry managers, who now know that low rainfall in typical La Niña winters increases fire risks the following spring and summer, especially in southern Florida. From 1981-98, La Niña years averaged 500,000 acres burned in Florida, compared to 200,000 acres for neutral years (Jones, Shriver and O'Brien 1999).

The potential value of ENSO forecasting to agriculture is estimated to be $100 million annually to southeastern U.S. farmers (Adams et al. 1995) and $200 million nationally (Solow et al. 1998).[2] Not all damages are avoidable, nor can all potential gains be secured, since forecasts are imperfect and dissemination may be impeded by technical, financial, and cultural barriers (Stern and Easterling 1999; Glantz 1996; Feldman 1989). Surveys of ENSO forecast value for agriculture include Johnson and Holt (1997), Mjelde et al. (1998), Weiher (1999) and Richard Katz' internet site (www.esig.ucar.edu/HP_rick/agriculture.html).

In this paper we discuss what climate variability and ENSO are and why they are important for Florida's agriculture. We also discuss which regions, commodities, and production technologies are most vulnerable. We then make the case for climate forecasting as an emerging technical improvement that enables producers to avoid some of the potential damages associated with climatic variability and also to take advantage of some profitable opportunities. As is true of other technical improvements for agriculture, there is no guarantee that researchers will provide the climate forecast products farmers want most nor that farmers will understand how best to use climate forecasts. Nor will climate forecasts necessarily improve economic performance immediately, but only in the longer term. A successful forecasting process will require not only that researchers produce accurate[3] forecasts and that farmers incorporate them into their decisions, but also that the forecast producers and users communicate with one another.

What is climatic variability?

The relationship between sea surface temperatures in the equatorial Pacific and agricultural productivity in the southeastern U.S. is just one facet of the new understanding of climate variability that has emerged over the past 20 years. We give ENSO particular emphasis because in many parts of the world it is the largest source of climate variability on seasonal to inter-annual scales. In the winter of 1982-1983, one of the strongest El Niño events measured this century developed undetected in the waters of the tropical Pacific. California and the Gulf Coast were battered by strong winter storms, while other parts of the country were drier and warmer than normal. The event opened the eyes of the nation as well as the scientific community to the potential climate impacts caused by fluctuations in sea surface temperatures of the equatorial Pacific Ocean. Year-to-year variability of climate influences many aspects of our daily lives, with impacts ranging from our comfort level when we work or travel to disasters such as hurricanes and floods, and can also influence the productivity and safety of our work. The agriculture and forestry industries are particularly vulnerable to variations in climate.[4] With a heightened awareness of El Niño- and La Niña-driven climate patterns, these sectors have expressed the need for more detailed information on which to base their decisions.

Recorded as far back as the 1500's, unusually warm water appeared periodically off the coast of Peru. This often occurred around Christmas, thus the phenomenon was called El Niño for the Christ child. Satellite measurements and moored buoys now show that the warm waters of an El Niño extend along the equator well out into the equatorial Pacific. Normally, trade winds blow from east to west, piling up warm water around Indonesia and Australia. During an El Niño, the trade winds die down and the warm water moves back towards the South American coast, resulting in sea surface temperatures that are much warmer than normal. In a La Niña, stronger than normal trade winds bring up cooler water from the ocean's depths, causing the sea surface to be colder than normal. Although El Niño and La Niña tend to return every 2 to 7 years, sea surface temperatures in the tropical Pacific are neutral, or near normal, a majority of the time. In fact, neutral years outnumber El Niño or La Niña years by over 2 to 1. Table 1 lists ENSO events of the previous century.[5]

The jet stream is a fast moving ribbon of air that circles the globe several miles above the ground. The jet stream is responsible for steering storms and fronts, driving the day-to-day weather we experience. In an El Niño winter, the warm surface waters of the Pacific provide heat and moisture that strengthens the jet stream, pulls it further south and keeps it flowing west to east across the southern United States. The new position guides winter storms

Table 1
Warm and Cold JMA ENSO Years between 1900 and 1999

ENSO Phase	Years
Warm (22)	1902, 1904, 1905, 1911, 1913, 1918, 1925, 1929, 1930, 1940, 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997
Cold (25)	1903, 1906, 1908, 1909, 1910, 1916, 1922, 1924, 1938, 1942, 1944, 1949, 1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1974, 1975, 1988, 1998, 1999

Note: Years not listed are neutral.

into California and along the Gulf Coast. These storms provide abundant rainfall and cooler temperatures for Florida and the deep South. In La Niña winters, a weaker jet stream strays to the north and meanders across the country. Fronts and storms do not make it down to Florida as often, and the winters are warmer and dryer than normal. For more details on climate variability and ENSO, the interested reader can see the NOAA/Office of Global Programs web site at http://www.ogp.noaa.gov/enso/.

How does ENSO affect Florida's temperature and precipitation?

One way to appreciate how ENSO influences climate in Florida is to examine how temperature and rainfall patterns differ during a Niño or Niña event. Figures 1 and 2 show how the relative frequencies of precipitation, daily minimum temperature and daily maximum temperature vary according to ENSO phase. As examples, we chose three locations (Tamiami, Ocala, and Madison) somewhat arbitrarily, but we have placed the same information for 80 weather stations statewide online at http://fawn.ifas.ufl.edu/enso.html. The climate data shown in these figures are from the U.S. Cooperative Station Network, and were archived and quality controlled by the National Climatic Data Center. We have used only observations from 1948 through 1999, since data quality and missing values were a concern for earlier observations. For each station, monthly averages of temperature and precipitation were computed for Niño, Niña, and neutral years. When plotted, these relative frequencies of precipitation, daily minimum temperature and daily maximum temperature show the areas of Florida most affected by ENSO.

Precipitation. In the absence of irrigation, inadequate water availability is the most important factor limiting crop production. Excess water also can affect crops adversely by damaging root systems, leaching plant nutrients, favoring development of some diseases, and sometimes delaying field operations. The critical period for rainfall deficit is from March to May in most of the state. The deficit is likely to be more severe in April in northern Florida, and in March in southern Florida during La Niña years. Rainfall deficit is generally less (equivalently, surplus is greater) in El Niño years from January to March.

One of the most striking impacts is the increase in average winter (November to March) rainfall during El Niño years, and the decrease in La Niña years (Figure 1). This graph shows likely conditions at the Tamiami and Ocala weather stations during El

Figure 1
Precipitation in Niño and Niña Years

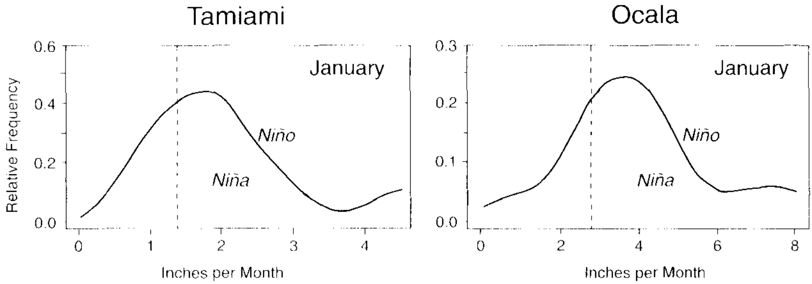
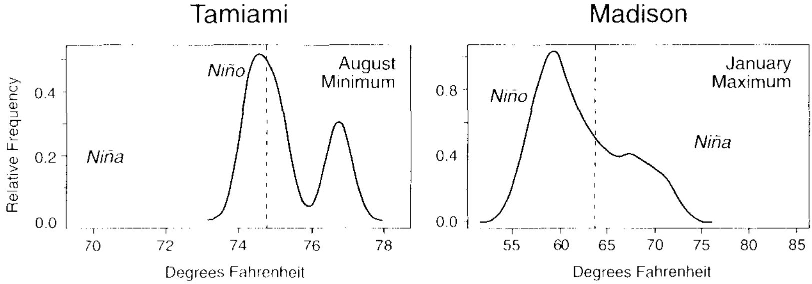


Figure 2
Daily Temperatures in Niño and Niña Years



Niño (solid line) and La Niña (dashed line) years. The more likely rainfall amounts are indicated by high values on the graph. Less likely conditions are represented by lower values. The relative frequencies of daily rainfall in January allow comparisons of conditions expected in El Niño and La Niña years, with the average in neutral years (dotted vertical line). Florida is particularly vulnerable to variations in seasonal rainfall, with an excess of over 30% of the normal total across much of the state during an El Niño winter. La Niña has the opposite effect, with deficits of 10% to 30% lasting from fall through winter and spring. The monthly deviation from normal due to either El Niño or La Niña conditions exceeds 30% in all of Florida, and 50% in the southern peninsula during some part of the year. The excess winter rainfall in El Niño years adversely affects yields of winter-harvested vegetables.

Temperature. Crops and animals are affected adversely when temperatures are either too hot or too cold. Different crops have different optimal temperatures. Because mammals regulate their body temperature, they tend to have wider optimal temperature ranges than crops, but experience heat stress at temperatures lower than many crops. Temperature also influences the rates of biological processes, and therefore the timing of flowering and harvest. Temperatures above or below critical target values also influence energy costs associated with heating or cooling. Changes in average daily maximum or minimum temperatures associated with El Niño or La Niña conditions are much smaller than the differences between seasons. However, departures from normal are significant in Florida, especially during winter months.

Figure 2 shows likely temperature conditions at the Tamiami and Madison weather stations during El Niño and La Niña years. The more likely minimum or maximum temperatures are indicated by high values on the graph. Less likely conditions are represented by lower values. The relative frequencies of temperatures allow comparisons of conditions expected in El Niño and La Niña years, with the average in neutral years (dotted vertical line). Florida and its Gulf Coast neighbors can expect to see average temperatures 2°F to 3°F below normal during El Niño years. La Niña has the opposite effect, with temperatures 2°F to 4°F above normal during winter months. La Niña's effect on temperature is more pronounced in northern Florida, and in Alabama and Mississippi. In the winter and spring months (December to April), average daily maximum temperatures are higher than normal in La Niña years, and lower than normal in El Niño years through

Florida. The effect of La Niña on winter temperatures increases as we move north within the state. The effects of El Niño and La Niña on winter average daily minimum temperatures is not as strong. In southern Florida, however, average daily minimum temperatures from June to August tend to be lower than normal in La Niña years. Lower nighttime temperatures may benefit growth and yield of some crops. However, in South Florida few commercial crops are grown in the summer.

Florida is a large and diverse state, climatically speaking, and ENSO is only one of many important influences upon our climate. One reflection of this complexity is that the climatic characteristics of principal agricultural interest tend to vary by region. In northern Florida and the Panhandle, for example, late hurricanes, the timing of frosts, and drought are most important, while in central Florida it is the occurrence of frosts and water allocations, and in southern Florida it is flooding and hurricanes (Hildebrand et al. 1999). While ENSO is by no means the only influence on our climate, its predictability is an opportunity that may benefit farmers throughout the state.

Who is vulnerable?

Climate variability and climate forecasting matter in a very practical sense to Florida farmers, although for some clearly more so than for others. Florida's agriculture is notable for both its economic importance and its diversity. Florida was the nation's ninth ranked state in 1998 in total farm sales of ($6.7 billion dollars). State farmers led the nation in the production of twenty major commodities, including citrus, ranked second in vegetables and horticulture, making it fourth in the nation in total crop sales (Florida Department of Agriculture and Consumer Services 1999). The magnitude and variety of agricultural production in Florida raise questions of which commodities and regions are most influenced by ENSO. An important conclusion of our statewide interviews with county extension agents was that the diversity of Florida's agriculture will place strong demands on a climate information system, making it essential to identify priority commodities and regions for technical assistance (Hildebrand 1999).

To properly gauge who is most affected, we must assess *vulnerability*, which is an aggregate measure of human welfare that integrates environmental, social, and economic exposure to climatic fluctuations (Bohle et al. 1994; Pulwarty and Riebsame

1997). The question of who is at risk depends critically upon location, as the previous sections show, but also upon the commodities produced and the production technology used. The most vulnerable producers and regions are those most exposed to climatic perturbations, whose production is most affected and least able to cope with climatic impacts, and who have more limited endowments for recovery (Bohle et al. 1994). To identify those most vulnerable, we have examined various measures of agricultural productivity (e.g., yields, crop value) and production technology for evidence of an ENSO influence.

To identify cropping enterprises in Florida vulnerable to ENSO, we analyzed the influence of ENSO phases on historical yields of annual field crops (maize, soybean, peanut), sugarcane, vegetables (potatoes, eggplant, strawberry, celery, pepper, tomatoes, snap bean, and sweet corn) and citrus (oranges, limes, grapefruit, temples, tangelos and tangerines). We found that several of Florida's high-valued crops are influenced by ENSO. These effects include decreased winter yields of tomato (77% of long-term average for neutral years), bell pepper (77%), sweet corn (83%) and snap beans (83%) in Niño years; increased prices of bell pepper and snap bean (each by 31%) in Niño years; increased sugarcane yields (107% of long-term average) following Niña events; and increased yields of grapefruit (109%) and tangerines (116%) but decreased lime yields (86%) in the harvest following Niño events (Hansen et al. 1998, 1999b). We attribute the yield responses to increased (decreased) rainfall, and reduced (increased) daily maximum temperatures and solar radiation in El Niño (La Niña), principally in winters but in spring and summer also.

Parallel research for the four-state region of Alabama, Florida, Georgia and South Carolina, found that ENSO has a significant influence on corn and tobacco yields, areas of soybean and cotton harvested, and total values of corn, soybean, peanut, and tobacco. In these four states, there is almost $500 million difference in the annual value of these four crops due to ENSO (Hansen et al. 1999a). A subsequent analysis that added the states of Mississippi, Louisiana, Tennessee, and North Carolina found that yields of cotton, tobacco, corn, tomato, hay, sugarcane, wheat, soybean, peanut, and rice all responded significantly to ENSO phase (Hansen et al. 2001). Thus, although ENSO-related weather variability explained a significant portion of yield variability of a broad range of crops in Florida and neighboring states, the direction, magnitude and timing of the effect depended on the particular crop.

Vulnerability also depends on the type of agriculture. Because it can reduce or eliminate water stress and is also observable, irrigation capacity is a particularly useful indicator of production technology that is less vulnerable to climate variability. Irrigation also correlates with crop type, geography, farm size and other factors (e.g., low income or cash flow) often cited as components of vulnerability. Our data sources for irrigation are the most recent and comprehensive available, the 1997 Census of Agriculture and the 1998 Farm and Ranch Irrigation Survey, which report those farmers who irrigated any of their land during the year (USDA/NASS 1999a, 1999b). Because these sources report whether a given farmer did irrigate rather than whether that farmer has the capability to do so should the need arise, the numbers we report are likely to slightly under-represent true irrigation capacity.

Although Florida has a humid climate, irrigation is widespread in crop production. According to the 1998 Farm and Ranch Irrigation Survey, Florida irrigated 1.862 million acres in 1997, or 3.4% of the U.S. total, which is the most of any state east of the Mississippi River and the tenth highest in the U.S. Of Florida's 34,799 farms, 12,673 had irrigation on some of the 4.567 million acres they managed. Florida's irrigated acreage represented just over half (51%) of its total cropland of 3.64 million acres.

Irrigation capacity is also an indication of wealth, which is often cited by economists (e.g., Hardaker et al. 1997) as what enables some producers to withstand income fluctuations better than others. Wealthier producers tend to have larger farms with more advanced production technologies and may also have greater access to risk hedging opportunities. The high correlation of irrigation capability with farm size is consistent with economists' depiction of wealth as risk bearing capital. According to the 1997 Census of Agriculture, some 1,112,860 irrigated acres, or 60% of Florida's total, was controlled by the 369 farms (3% of the total) having at least 2000 acres. The 708 farms (5.6%) having at least 1000 acres controlled 1,339,603 irrigated acres (72%).

Annual sales are another index of producer wealth, and farmers who irrigate have a disproportionately large share of sales. According to the 1997 Census of Agriculture, the average market value of agricultural products sold per farm in Florida is higher for farms having irrigated land ($382,683) than for either non-irrigated farms ($52,192) or for all farms ($149,586). The same is true for the average value of crops sold: irrigated ($405,620), non-irrigated ($48,354), and all farms ($284,876). However, non-irrigated farms also had lower expenses: non-irrigated ($43,326), irrigated ($267,638) and all farms ($126,043). On average, irrigated farms also have more valuable machinery and equipment ($67,767) than do non-irrigated farms ($25,156).

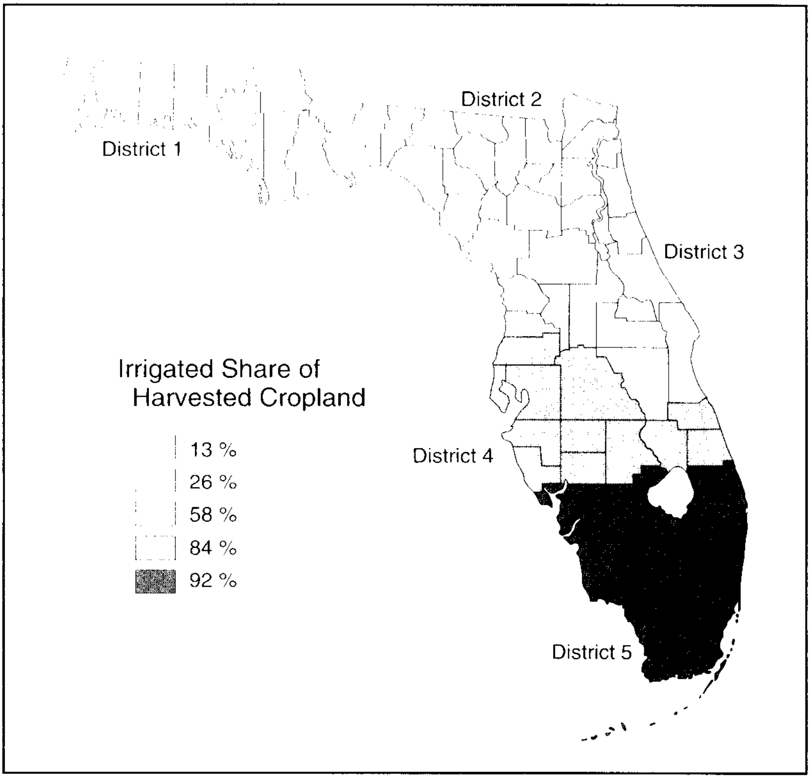
Not surprisingly, irrigation produces higher crop yields. Table 2 compares the irrigated versus non-irrigated yields for several crops that are grown under both irrigated and rainfed conditions in Florida. In each case, irrigation makes a substantial difference in crop yields. Since irrigation is generally only part of a package of improved management, not all the improvement in yields can be attributed to it. Nonetheless, irrigation plays a critical role (Paxton and Lavergne 1989). Since irrigation raises average yields by improving the driest conditions, it also tends to reduce yield variability, an important source of income risk. Notably the crops in Table 2 are grown in the northern and panhandle regions of the state, while crops cultivated only under irrigated conditions (e.g., vegetables, citrus, sugarcane, horticulture) are grown in the central and southern regions of the state. Figure 3 maps the proportion of harvested cropland that is irrigated, according to the 1997 Census of Agriculture, using the University of Florida/ Institute of Food and Agricultural Science's Extension District boundaries for regions of comparison. The higher irrigated shares of harvested cropland in the central and southern portions of the state indicate less ENSO vulnerability and suggest that the problems that do exist there stem from too much precipitation rather than too little.

Table 2
Harvested Crops and Irrigation

Crop	Irrigated Share (% area)	Irrigated Yield (per acre)	Rainfed Yield
Corn (bushels)	21	111.4	69.9
Soybeans (bushels)	6	35.6	24.4
Peanuts (lbs)	20	3226.2	2626.5
Cotton (bales)	7	698	415
Tobacco (lbs)	81	2424.9	2051.1

Sources: 1997 Census of Agriculture and 1998 Farm and Ranch Irrigation Survey.

Figure 3
Irrigation Capacity by IFAS Extension District



Finally, policy and technical changes can make farming more vulnerable to climate variability. Florida's winter fresh tomato growers and distributors, and the competition they face from Mexico, are a case in point. Florida and Mexico are historic rivals for the U.S. winter tomato market, but Mexico has improved its market share for at least three reasons. First, Mexican adoption of extended shelf life varieties and drip irrigation technology in recent years has lowered their input costs and raised yields, while Florida's yield trend has remained flat and its input costs are rising (Love and Lucier 1996). Second, the devaluation of the Mexican peso, which lost over half its value relative to the US dollar in 1995, increased the volume of Mexican tomato exports to the US by 70 percent during the 1995/96 season. Because the Mexican tomato export price may not rise in response to a peso devaluation for several months, such devaluations have the temporary effect of an export subsidy proportional to the magnitude of the devaluation (Douglas 1997). Third, the North American Free Trade Agreement, which took effect in 1994, has reduced tariffs on imported tomatoes and will eliminate them by 2003. As a result of competitive pressures stemming from changes in trade policy and recent trends in yields and input costs, Florida's winter tomato producers and distributors are vulnerable to a wide range of risks, including climate variability.

Our assessment of vulnerability suggests a potential for farmers throughout the state to modify practices based on forecasted ENSO phase. Previously, our interviews with extension agents informed us that livestock producers, too, are highly interested in climate forecasts, since pasture establishment, hay purchases, and animal sales decisions could be informed by climate forecasts so as to reduce producer risks (Hildebrand 1999, 2000). Unfortunately, the widespread physical impact of ENSO in Florida does not imply that all producers have the same capacity or flexibility to adjust their decisions in light of a climate forecast. For example, perennial crops such as citrus and forestry have fewer mitigatory actions available, as compared to annual row crops. While citrus growers did alter their replanting patterns and varietal mix following the severe freezes in central Florida in the 1980s, this was a response to a longer scale of climate change rather than to seasonal or inter-annual climatic variability (Miller 1991). Our goal of reducing vulnerability to climate fluctuations requires a look at potential responses to climate forecasts.

How can farmers respond?

Translating even an accurate climate forecast into a successful response for farmers is a complicated task. Consider the following example, reported to us at a meeting with 175 peanut farmers in Marianna, Florida, in March 1999. In 1998 some peanut farmers in northern Florida and southern Georgia, aware that it was an El Niño year, delayed planting due to excessive spring rains. Those who did so avoided the catastrophic losses due to heat and drought stress that would later be experienced by those who did plant early. However, yields varied spatially due, in part, to the timing of regional precipitation associated with a hurricane. Yields were quite good in southern Georgia, but generally poor in Florida.

This experience highlights the timing of weather events and the importance of climate influences perhaps not related to ENSO, and suggests the need for a small geographic focus when applying climate forecasts to crop production.

The question of an appropriate response is partly one of what researchers can recommend farmers should do after a given climate forecast. Some management variables worth considering as possible responses to a forecast are the crop mix and cultivars selected for a given year, the amounts of fertilizers and pesticides used, and the planting dates. Cold protection, land drainage and irrigation scheduling are other possibilities. According to one recent climate forecast evaluation for Tifton, Georgia, adjusting crop mix in small to medium field crop farms could increase profits by 4–6 $/ha; and varying planting date, variety, plant population and nitrogen fertilizer applications has potential benefits of 5–30 $/ha (Royce et al. 1998). An important advantage agriculture has, relative to other economic sectors, is the availability of crop models that allow exploration of the outcomes of numerous alternative decisions, which would be impossible to do with traditional field experiments or statistical analyses of historical data.

However, as the peanut example above suggests, the issue of forecast usefulness or value extends beyond forecast skill and the availability of forecast responses. Producers' decisions whether to use climate forecasts are complex and do not occur in isolation from their other decisions. Pulwarty and Redmond (1997) argue that forecast "interpretation" involves ongoing evaluation of the physical conditions being forecast, in the context of other decisions and information that potential users must consider throughout the year.

Climate forecasters do offer a valuable technology to Florida's farmers: the predictability of climate and yield variability associated with ENSO suggests a potential to tailor agricultural production decisions to either mitigate the negative impacts of adverse conditions or to take advantage of favorable conditions. For climate forecasts to appeal to farmers, however, they (1) must address climatic variables of interest at (2) a sufficient level of spatial resolution. They (3) also must arrive prior to decision making, and (4) should come from a trusted information source. So, to facilitate use by fruit and vegetable growers, for example, forecast providers might enlist a cooperative association such as the Florida Fruit and Vegetable Association, to aid forecast structure, timing and delivery. Also, working with more specialized cooperatives for both producers (e.g., the Florida Tomato Grower Exchange) and distributors (e.g., the Florida Tomato Exchange) might help target climate information toward the different needs of these groups. Finally, forecast providers might consult important input suppliers, such as seed distributors or the South Florida Water Management District, to determine if the recommended mitigatory responses are in fact feasible. The usefulness of a climate forecast will depend in part upon the capability of users to process that information so that it can match their needs (Stern and Easterling 1999).

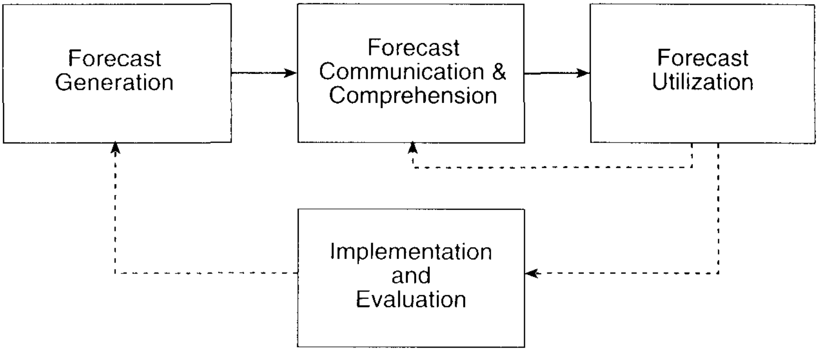
The bottom line is that, to reduce vulnerability, climate forecasts must be used to modify decisions. The skill of a forecast, the feasibility of a response, and the effectiveness of communication each make an essential contribution to forecast value.

Building a better climate forecasting process: the Florida Consortium

Translating imperfect ENSO-related climate forecasts into information useful for improved decision making is a complex issue that goes well beyond simply producing better climate forecasts. Vulnerability of Florida's agriculture and economy to climate fluctuations and weather extremes prompted formation in 1996 of a consortium of Florida universities (Florida State, Florida and Miami) to capitalize on the potential predictability of climate impacts associated with ENSO (www.coaps.fsu.edu/lib/Florida_Consortium/). The goal of our research in the Southeast US is to reduce economic risks and improve social and economic well being by facilitating the routine and effective use of climate forecasts for agricultural decision making.

The Florida Consortium has designed an operational system for the dissemination of agriculturally relevant climate information in Florida. The conceptual framework for this forecasting system (Figure 4) includes four parallel activities associated with (a) the generation of climate information, (b) the communication and comprehension of such information, (c) the use of the information, and (d) implementation and evaluation. As Sarewitz et al. (2000) note, good decisions are more likely to occur when all components of a forecast system function well. In our work in the southeastern US, we have explored extensively the functions of each of these components and how they fit together. The implementation and

Figure 4
Integrated Components of a Forecasting System



Adapted from: Sarewitz, Pielke and Byerly 2000. Prediction. *Island Press. Page 376*

evaluation portion of the system, in particular, is the result of a close collaboration between the Consortium and the Florida agricultural extension system.

Our attempts to build a climate forecasting system in Florida would be naïve and likely counter-productive if we did not recognize and, indeed, take advantage of the agro-technological infrastructure already in place. We have striven to instill among ourselves the notion that the only way to perform work on applications of climate information is through multi-disciplinary, multi-institutional collaboration and active involvement of decision makers from the start. The Florida agricultural extension system has emerged as our major partner, providing the conduit for information flow from our research effort to end users, and helps guide and prioritize our research efforts. Through this partner, we are able to greatly amplify the impact of our research and ensure sustained delivery and use of climate information and decision aids in the future. Our close cooperation with the Florida agricultural extension system is allowing us to evolve from a purely research-oriented project to a proto-operational effort, and has three motivations. First, the experience of the extension system in facilitating other types of agro-technological transfer may help us understand how to achieve the dissemination of climate information effectively. Second, the extension system provides a readily available infrastructure for the delivery of information and for the evaluation of its effectiveness. Third, the existing relationship of trust that extension already enjoys with farmers will enable the iterative bridging process between forecast producers and users.

If improved agricultural decision making is our goal, then climate forecasting may best be thought of as a social process rather than simply as a meteorological product that farmers will use and use correctly. Because climate forecasts will always be imperfect and difficult to evaluate, policy officials should focus on reducing producers' vulnerability to climate fluctuations. That means, in part, a goal of improving long term measures of income loss or gain without giving undue emphasis to potentially misleading short term variations. To reduce vulnerability to climatic variability within a forecasting system, the researchers, extension system, trade groups, producers, and other forecast users all will play critical roles. Because the benefits of reducing exposure to climatic variability are likely to be unevenly distributed, research and extension efforts must be carefully targeted to the specific sub-populations and locations that are most vulnerable.

Notes

[1] To make clear the distinction between weather and climate, consider the example of a hard freeze in Central Florida that lasts for 2-3 days, which is a weather event. In contrast, one's heating bill may be smaller due to a warmer winter, which is a climatic pattern.

[2] Global climate change could alter the frequency and severity of ENSO events. One recent paper suggests that extreme ENSO events may become more frequent with a global warming (Timmermann et. al 1999). The economic consequences from a strong Niño for U.S. agriculture are a loss of $1.5 to $1.7 billion and a $2.2 to $6.5 billion loss for a strong Niña (Adams et al. 1999).

[3] What constitutes a "good" forecast process is a subject of spirited debate, of which technical accuracy is a part. Multiple measures are needed to evaluate the technical, communication, and use dimensions of forecasts. Physical scientists have evaluated forecasts according to technical criteria, such as skill scores and critical success indices, while social scientists have studied the forecast communication process. Another way to evaluate a forecast is to consider whether it had value to decision makers (Pielke 2000).

[4] The high variability of agricultural income is one reflection of

agriculture's vulnerability to climate fluctuations. Consider the statewide average over the period 1960-1999. According to the U.S. Department of Agriculture, National Agricultural Statistics Service, the average income expressed as a return to capital was 9.24%, which comports fairly well with the rule of thumb that we try to earn 10% on our investments. However, the variability of this return, expressed as a standard deviation, was 6.53, or 71% of the average return. That degree of variability does much to explain the agricultural community's interest in climate forecasts.

[5] We define ENSO phase in terms of the Japanese Meteorological Agency's sea surface temperature anomaly index (JMA SSTA), which selects well the known ENSO events. Several alternative ENSO phase definitions exist and are based on either atmospheric pressure patterns or on sea surface temperature anomalies in the tropical Pacific Ocean (Trenberth 1997). Our definition (Table 2) is a 5-month running mean of spatially averaged SST anomalies over the tropical Pacific: 4ES-4EN, 150EW-90EW. If the running mean exceeds 0.5EC for 6 consecutive months (including OND), we categorize the ENSO year of July to the following June as warm (El Niño). If the running means are less than or equal to -0.5EC over that time span, we classify the year as cold (La Niña or El Viejo). For all other possible index values, we define the year as neutral. JMA SSTA index values for each month of the 1868-1999 period are available via ftp. (www.coaps.fsu.edu/pub/JMA_SST_Index/).

Acknowledgements

This research has been supported by grants from the National Oceanic and Atmospheric Administration (Office of Global Programs) and the National Science Foundation (Methods and Models for Integrated Assessment Initiative) to a Consortium of Florida Universities (University of Miami, University of Florida and the Florida State University).

References

Adams R.M., Chen C.C., McCarl B.A. and Weiher R.F. (1999) "The Economic Consequences of ENSO Events for Agriculture." *Clim Res* 13: 165-172

Adams R.M., Bryant K, McCarl B.A., Legler D., O'Brien J.J., Solow A., Weiher R.F. (1995) "Value of Improved Long-Range Weather

Information." *Contemp Econ Policy* 13: 10-19

Bohle H.G., Downing T.E., Watts M.J. (1994) "Climate Change and Social Vulnerability." *Global Environmental Change* 4(1): 37-48.

Changnon S.A. (1999) "Rapidly Expanding Uses of Climate Data and Information in Agriculture and Water Resources: Causes and Characteristics of New Applications." *Bull Am Meteorol Soc* 80: 821-830

Changnon, S.A. (2000) "Impacts of El Niño's Weather" In *El Niño 1997-98: The Climate Event of the Century*. S.A. Changnon, (ed). New York: Oxford Univ Press. Pp. 136-171.

Douglas C.D. (1997) "The Impact of Exchange Rate Adjustments on the United States Fresh Tomato Industry: Policy Implications for the United States and Mexico." Unpublished Ph.D. dissertation, Gainesville: Univ Florida, Dept of Food and Resource Economics.

Feldman M.S. (1989) *Order without Design: Information Production and Policymaking*. Palo Alto: Stanford Univ Press.

Florida Consortium (1999) *El Niño, La Niña and Florida's Climate: Effects on Agriculture and Forestry*. Available online at http://fawn.ifas.ufl.edu/nino/

Florida Department of Agriculture and Consumer Services (2000) *Florida Agricultural Facts: 1999 Edition*. Tallahassee: Florida Dept Agricultural and Consumer Services.

Glantz M.H. (1996) *Currents of Change: El Niño's Impact on Climate and Society*. New York: Cambridge Univ Press.

Hansen J.W., Irmak A., Jones J.W. (1998) "El Niño-Southern Oscillation Influences on Florida's Crop Yields." *Soil and Crop Science Society of Florida Proceedings* 57: 12-16.

Hansen J.W., Hodges A.H., Jones J.W. (1999a) "ENSO Influences on Agriculture in the Southeastern United States." *J Climate* 11: 404-411.

Hansen J.W., Jones J.W., Kiker C.F., Hodges A.H. (1999b) "El Niño-

Southern Oscillation Impacts on Winter Vegetable Production in Florida." *J Climate* 12: 92-102.

Hansen J.W., Jones J.W., Irmak A. and Royce F. (2001) "ENSO Impacts on Crop Production in the Southeast US." Chapter 4 in *Impacts of El Niño and Climate Variability on Agriculture.* ASA Special Publication, American Society of Agronomy. Madison, WI.

Hardaker J.B., Huirne R.B.M., Anderson J.R. (1997) *Coping with Risk in Agriculture.* New York: CAB International.

Hildebrand P. (ed). (1999) "Potential Use of Long Range Climate Forecasts by Agricultural Extension Agents in Florida." Florida Consortium Technical Report FC-UF-2000-01.

Hildebrand P. (ed). (2000) "Potential Use of Long Range Climate Forecasts by Livestock Producers in North Central Florida." Florida Consortium Technical Report FC-UF-2000-02.

Johnson S.R., Holt M.T. (1997) "Value of Weather Information" In: Katz R.W., Murphy A.H. (eds) *Economic Value of Weather and Climate Forecasts.* New York: Cambridge Univ Press.

Jones C.S., Shriver J.F., O'Brien J.J. (1999) "The Effects of El Niño on Rainfall and Fire in Florida." *Florida Geographer.* 30: 55-69.

Love J., Lucier G. (1996) "Florida-Mexico Competition in the United States Market for Fresh Vegetables." Vegetables and Specialties Situation and Outlook Report VGS-268. Washington, D.C.: US Dept Agriculture, Economic Research Service.

Mjelde J.W., Hill H.S.J., Griffiths J.F. (1998) "A Review of Current Evidence on Climate Forecasts and Their Economic Effects in Agriculture." *Am J Agric Econ* 80: 1089-1095

Miller K. (1991) "Response of Florida Citrus Growers to Freezes of the 1980s." *Clim Res* 1:133-144.

Paxton K., Lavergne D. (1989) "Irrigation and Potential Diversification Benefits in Humid Climates." *So J Agric Econ* 21(2): 167 - 174.

Pielke R.A. Jr. (2000) "Policy Responses to El Niño 1997-98." In *El Niño 1997-98: Climate Event of the Century.* pp. 172-196. S.A. Changnon, (ed) New York: Oxford University Press.

Pulwarty R.S., Riebsame W.E. (1997) "Political Ecology of Vulnerability to Hurricane-Related Hazards." Pp. 185-214 in *Hurricanes: Climate and Socioeconomic Impacts.* H.F. Diaz, R.S. Pulwarty, (eds) Berlin: Springer.

Royce F.S., Hansen J.W., and Jones J.W. (1998) "Optimization of agricultural management using crop models and simulated annealing." *Agronomy Abstracts.* American Society of Agronomy, Madison WI.

Sarewitz D., Pielke R.A. Jr., Byerly R. Jr. (2000) *Prediction: Science, Decision Making and the Future of Nature.* Covelo, CA: Island Press.

Solow A., Adams R., Bryant K., Legler D., O'Brien J., McCarl B., Nayda W., Weiher R. (1998) "Value of Improved ENSO Prediction to US Agriculture." *Clim Change* 39: 47-60

Stern P.C., Easterling W.E., (eds) (1999) *Making Climate Forecasts Matter.* National Research Council, Panel on Human Dimensions of Seasonal-to-Interannual Climate Variability. Washington, D.C.: National Academy Press.

Timmermann A., Oberhuber J., Backer A., Each M., Latif M., Roeckner E. (1999) "ENSO Response to Greenhouse Warming." *Nature* 398: 694-697.

Trenberth K. (1997) "The Definition of El Niño." *Bull Am Meteorol Soc* 78(12): 2771-2777.

USDA/NASS (1999a) *1997 Census of Agriculture.*

USDA/NASS (1999b) *1998 Farm and Ranch Irrigation Survey.*

Weiher R., (ed). (1999) *Improving El Niño Forecasting: The Potential Economic Benefits.* Washington, D.C.: US Dept. Commerce/NOAA/Office of Policy and Strategic Planning.