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Chapter Seventeen

EL NIÑO AND PERU: A NATION'S RESPONSE TO INTERANNUAL CLIMATE VARIABILITY

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INTRODUCTION

For at least one century, local fishermen along the northern coast of Peru have observed that, generally near the end of each calendar year, a warm ocean current would extend southward along the coast. As it occurred around Christmastime, they termed this current "Corriente del Niño", or "El Niño Current", referring to the Christ child. In recent decades, however, the term "El Niño" has become popularly used in reference to an incidence of exceptionally warm water appearing every 2-9 years along the equator and extending down the west coast of South America. The intrusion of this warm surface water suppressed the upwelling of colder, nutrient-rich water from below, inhibiting productivity. It has been blamed for the death and displacement of countless species of fauna and flora along the west coast of South America, as well as for having contributed to the collapse of the once-thriving Peruvian anchoveta fishery. Climate scientists link this oceanographic phenomenon with a related atmospheric event referred to as the "Southern Oscillation", arriving at the term El Niño-Southern Oscillation (ENSO). The Southern Oscillation is, as described by Trenberth (1991),[1] "a see-saw in atmospheric mass involving exchanges of air between eastern and western hemispheres in tropical and subtropical latitudes with centers of action located over Indonesia and the tropical

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South Pacific Ocean." Evidence suggests that the ENSO phenomenon contributes to, or is responsible for, anomalous weather patterns throughout the world, sometimes of disasterous proportions. For example, the 1982/83 ENSO, the strongest event of the century, has been held responsible for widespread incidents of drought, flooding and severe storms in 5 continents, resulting in several hundred deaths, and damages estimated at $8.65 Billion (Canby, 1984).[2] Peru was one of the countries most severely impacted by this event having suffered hundreds of deaths, and an estimated $2 Billion in damages to agriculture, fisheries, transportation, housing and other sectors of the economy.

The tremendous societal consequences related to ENSO have prompted 18 nations to support hundreds of scientists in a coordinated research effort to gain an understanding of the dynamics of this phenomenon in order to ultimately be capable of predicting its occurrence months in advance. Our understanding of ENSO has improved a great deal in recent years. It now appears that in some regions of the world the occurrence of an ENSO is closely related to local climatic variability; that is, to the timing and magnitude of seasonal rainfall. Scientists in a few countries, such as Peru, Brazil, Ethiopia, Australia and India, have begun applying knowledge of the dynamics of ENSO to forecast the associated climatic consequences. Effectively applied, these forecasts can be used to mitigate the socio-economic impacts of interannual climate variability on the local population. The best example of a nation applying recent scientific findings about ENSO in an effort to mitigate the socio-economic impacts associated with this natural phenomenon can be found in Peru.

This chapter describes the anomalous precipitation and temperature patterns observed in the agricultural, northwestern region of Peru during the 1982/83 ENSO, and analyzes the subsequent efforts by the Peruvian Government to mitigate the adverse socio-economic impacts due to variability in their climate. Finally, some actions which need to be taken in order to improve our ability to predict interannual climate variability, and to better prepare policy-makers throughout the world in the use of these predictions, are suggested.

EL NIÑO - SOUTHERN OSCILLATION (ENSO)

The mean annual climate cycle in the Pacific is determined by a complicated interplay between the temperature of the ocean water at the surface, or sea surface temperature (SST) patterns, featuring an extensive warm pool in the west, and a cold tongue of water just south of the equator in the east, and atmospheric circulation patterns, dominated by relatively light winds in the west and strong trade winds further east. The cold water along the coast of South America can be attributed to upwelling of deeper waters, rising to replace surface waters being pushed westward and equatorward by the prevailing winds, and affected by the rotation of the earth. These patterns determine, in great part, the light precipitation generally observed along the west coast of South America during non-ENSO, or "normal" years.[B]

Although no two ENSO events are exactly alike in their intensity (defined by the size of departure from average SSTs), geographic manifestation, duration or impacts, some general statements can be made to characterize the phenomenon. During ENSO years, a weakening or collapse of the predominant easterly winds in the central and eastern tropical Pacific, along with associated anomalous SST warmings, result in a shift in precipitation patterns throughout the region. The low pressure area which normally sits over eastern Indonesia shifts eastward, taking with it the associated atmospheric convection, and hence precipitation, into the central Pacific. ENSOs have been characterized as consisting of four phases: a precursory phase, an onset phase, a phase when the anomalous conditions grow and mature, and a phase during which anomalous conditions decay, lasting anywhere between 6 and 24 months (Nicholls, 1987).[3]

Understanding of the dynamics of this recurring climate phenomenon has evolved over the decades. Sir Gilbert Walker observed interannual fluctuations in atmospheric pressure over the low pressure region in the western Pacific and high pressure region in the eastern south Pacific. (Walker, 1923).[4] This recurring fluctation became known as the Southern Oscillation (SO) The Southern Oscillation Index (SOI), defined as the atmospheric pressure at Tahiti minus the pressure at Darwin, Australia has been a useful indicator for the monitoring of ENSO. Walker and Bliss (1932)[5] recognized the relationship of the SO to tropical and subtropical weather phenomena. Berlage (1957)[6] was the first to show the strong correlation between the SOI and SST fluctations along the coast of Peru. Bjerknes (1966a, 1966b)[7,8] proposed a mechanism connecting the SO to El Niño, arguing that the coastal winds, weakened as a response to the weakened trade winds, reduce coastal upwelling, thus causing the anomalously warm El Niño Current. Wyrtki (1975)[9] proposed that, in fact, the warm waters appearing off the coast of Peru were in direct response to the weakening of the trade winds in the central and western equatorial Pacific, and not due to lighter-than-normal coastal winds. Normally, the easterly winds push the upper ocean water toward the western Pacific, deepening the thermocline and causing a rise in sea level in the west relative to the east. During an ENSO, when the winds relax, the warm water is displaced toward South America in a wavelike fashion, reversing the state; that is, causing the thermocline in the east to deepen, and the sea level to rise. For Peru, this marks the onset of an ENSO.

Although efforts to model the behavior of both the ocean and the atmosphere began as early as 1976, it is the occurrence of the very strong 1982/83 event that motivated unprecedented amounts of research directed toward predicting these episodes. Most of our current understanding of the dynamics of ENSO are as a result of models. These include physical-statistical methods (Barnett, 1984; Barnett et al., 1988);[10,11] linear dynamical models (Inoue and O'Brien, 1984);[12] and coupled

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[B]There is another recurring climatic phenomenon which is quite opposite to ENSO. These so-called "Cold Events" (which have also been referred to as "anti-ENSO" or 'La Niña") are characterized by generally opposite oceanographic and atmospheric manifestations (and climatic variations) as in the "warm" ENSO. A detailed description of this "cold" phenomenon is beyond the scope of this chapter, but it is worth mentioning that, generally, the climatic impacts in Peru during a Cold Event are opposite to those during ENSO. That is, instead of high precipitation, there is very light precipitation in the northeastern region.

ocean-atmosphere models (Cane, 1986).[13] In 1983, the ICSU Scientific Committee on Oceanic Research (SCOR) defined El Nino as the appearance of anomalously warm water along the coast of Ecuador and Peru as far south as Lima (12° S), during which a normalized SST anomaly exceeding one standard deviation occurs for at least four consecutive months at three or more of five coastal stations (Talara, Puerto Chicama Chimbote, Isla Don Martin and Callao.)

The current understanding is that the SO is caused by interannual SST variations in the tropical Pacific (Philander, 1990)[14] and that El Niño events are characterized by positive SST anomalies along the coasts of Ecuador and Peru and along the equator eastward of 130°W, and by an equatorward expansion and intensification of the Inter-Tropical Convergence Zone (ITCZ)[C] over the eastern Pacific (Deser & Wallace, 1990).[15]

THE SCIENTIFIC RESPONSE

In the 1970's, the World Climate Research Program (WCRP) was developed under the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU). Prediction of climate fluctuations emerged as one of its major objectives, and in the early 1980's a series of scientific workshops were convened to develop a comprehensive program for the study of interannual variability in the Tropical Ocean and Global Atmosphere (TOGA). The international TOGA Program officially began January 1985, and is scheduled to continue through December 1994. The scientific objectives of the research program, as defined within the International Scientific Plan (WCRP, 1985);[16] are: a) to gain a description of the tropical oceans and the global atmosphere as a time dependent system, in order to determine the extent to which this sytem is predictable on time scales of months to years; b) to study the feasibility of modeling the coupled ocean-atmosphere system for the purpose of predicting its variations on time scales of months to years; and c) to provide the scientific background for designing an observing and data transmission system for operational prediction, if this capability is demonstrated by coupled ocean-atmosphere models. The 10-year research program encompasses four major elements: a) *long term observations*, to define the time-dependent structure of the tropical oceans and the global atmosphere and the interactions at the ocean-atmosphere interface; b) *empirical studies*, essential for estimating the predictability of the coupled climate system and for understanding the processes that control the system; c) *process studies*, focussed on specific processes identified as critically important for an understanding of large-scale ocean-atmosphere interaction; and d) *modeling* efforts guided by the long-range goal of operational prediction (NRC, 1986).[17]

In 1990, the National Academy of Sciences commissioned a mid-term review of the TOGA Program, and concluded that a remarkable degree of progress has been made toward meeting the objectives of the program. The coupled ocean-atmosphere

[C]The ITCZ is defined as the band of atmospheric convergence which circulates the globe, parallel to, and north of, the equator. This is an area of high atmospheric convection, cloudiness and precipitation.

system over the Pacific is now being monitored in near real time using both *in situ* and satellite remote sensing techniques, and an ocean observing system adequate for initialization and verification of prediction models is near completion. A modest ability to simulate the ENSO cycle with computer models has been demonstrated, and a plausible hypothesis has been proposed to explain the physical basis for the predictive nature of ENSO. Hence, the initial elements of an observational and prediction system are in place. However, a great deal of work remains if the full potential of prediction of the behavior of the tropical oceans and their relationship with the circulation of the global atmosphere is to be realized (NRC, 1990).[18]

ENSO-RELATED PRECIPITATION PATTERNS IN PERU

The west coast of South America, from the northern coast of Chile toward the northern coast of Peru, is characterized climatalogically by light precipitation, resulting in a semi-arid to arid climate. Along the northwestern coast and in the Andean highland region seasonal rainfall patterns prevail. East of the Andes mountain range, in the Peruvian Amazon basin, precipitation occurs year-round, but is greatest during a September to April "rainy season." A rainy season is also experienced between September and April in the highland region, as contrasted with the northern coastal region where precipitation begins in January and ends in April of each year. Total precipitation generally decreases as we move away from the equator, and south of 7°S practically no precipitation falls. At the same time there is a general increase in total rainfall as a function of altitude. From time to time, the northern coastal region is subjected to intensive precipitation and flash floods, while other regions in the Andean highland are experiencing intensive droughts, resulting in severe social and economic hardship.

Two meteorological mechanisms determine the precipitation patterns in the northwestern region during a normal rainy season. First, there are convective processes associated with the seasonal peak of SST in the eastern equatorial Pacific. During austral summer, the ITCZ shifts equatorward until, the average, its southern boundary is located near northern Peru. Secondly, there is a westward displacement of convective processes and precipitation crossing over the Western Andean mountain range, providing much of the precipitation at higher altitudes along the coast.

The climatological precipitation averages recorded during the rainy season at representative sites along the northern coast of Peru are presented in Table 1. Note that the precipitation decreases with latitude but increases with altitude, as stated above.

During ENSO events, the ITCZ is observed to shift further south, even crossing the equator when the episodes are strongest. Furthermore, SST values off the coast reach 2°-12°C above normal, depending on the strength of the event. As a result of this southward shift of the ITCZ, atmospheric convection becomes more intense. This, combined with increased evaporation associated with higher SSRs, lead to relatively large increases in precipitation initially near the coast and then moving eastward. These increase are most pronounced at altitudes up to 300 meters, with more modest increases above that height. The dramatic increase in rainfall often results in flooding and mud slides along the western flank of the Andean mountain range.

Increases in precipitation in the northern coastal region of Peru during ENSO events are reflected in Fig. 1, which shows the relationship between anomalies observed in the SOI, the Puerto Chicama SST anomalies and the precipitation observed at Chulucanas during the rainy season. Due to the unique terrain around Chulucanas, which is located at an altitude of 95 meters, the moisture moving inland from the coast is more efficiently intercepted. As convective processes reach the Andean foothills, they become amplified, due to the regional topography, resulting in the development of large storm systems which then spread back across the desert areas.

A number of theories have been postulated to explain the precipitation patterns observed in Peru during the 1982/83 ENSO. For example, Horel and Cornejo-Garrido (1986)[19] suggested that atmospheric processes in the Amazon basin migrate westward and are responsible for the intensification of the storm systems in the northwestern region. On the other hand, Goldberg et al. (1987)[20] observed that storms originate near the coast and move eastward, reaching maximum intensity during evening and nighttime, and lasting 6 to 12 hours, or more. Satellite images of this event provide evidence that both processes contribute to the development of the storm systems.

SOCIO-ECONOMIC IMPACTS TO PERU

Historically, droughts and floods have been the greatest natural causes of famine in Peru, while earthquake-induced landslides have been among the most destructive throughout the Andean region. During ENSO events, heavy and repetitive convective rain storms have been the main cause for the devastating flash floods at the western Andean foothills and in the coastal plains region, whereas during Cold Events a lack of precipitation leads to droughts. The effects of droughts and floods on total food production have caused much human suffering and stress to society. Crop failures have lead to shortages of food and loss of employment, causing great social and political concern.

The most thorough compilation of the ocurrence of ENSO episodes during recorded history is given by Quinn et al. (1987),[21] whose analysis included the

TABLE 1.
Normal Precipitation (mm/month) along the northwestern coast of Peru

Name (Lat., Altitude)	Jan	Feb	Mar	April
Tumbes (3.5°S, 25m)	25	55	51	27
Talara (4.5°S, 50m)	3	8	7	3
Chulucanas (5.1°S, 95m)	21	59	109	27
Huarmaca (5 6°S, 2100m)	125	173	248	153
Chiclayo (6.5°S, 27m)	3	2	6	2

accounts of ENSOs found in documents related to the Spanish conquest. They identified the 1925/26 and 1982/83 events as the most severe of the 20th century. Evidence of historical catastrophic floods in Peru resulted from a study by Nials et al. (1979)[22] of the early irrigation system used in the coastal region. They found evidence that an ENSO 2-4 times the intensity of the very strong 1925/26 event occurred sometime within a century of 1100 A.D. Paleoclimatalogical records allow us to identify prehistorical events using proxy data such as cadmium content in tropical corals (Shen et al., 1987),[23] and oxygen isotope content in ice cores (Thompson et al., 1984).[24] These, and other proxy data related to climate change, are undergoing further study in Peru. Stratigraphic studies of the Casma floodplain, about 300 km north of Lima, have resulted in the identification of at least eighteen floods which have occurred over the past 7,000 years (Wells, 1990).[25]

The compilation of quantitative information on the impact of ENSO phenomena in Peru began after the 1972/73 event, when the Peruvian anchoveta fisheries collapsed. For this reason, impact studies originally focussed on the fisheries sector, and not on agriculture and other sectors. However, during the 1982/83 event, damage to the agricultural sector due to floods and drought exceeded that to

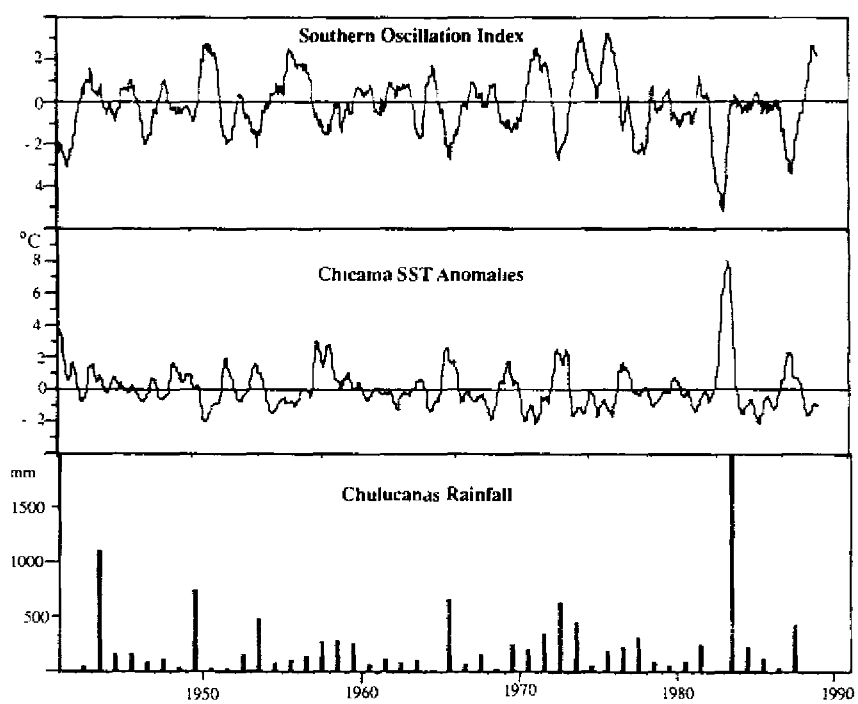

FIG. 1. Southern Oscillation Index, SST at Chicama, and rainfall at Chulucanas. The SOI is the five-month running mean of the difference between the standardized sea level pressure anomalies at Tahiti and Darwin (Tahiti-Darwin). The SST at Chicama is of the five-month running monthly means. The rainfall at Chulucanas is the accumulated seasonal (Jan-Apr) precipitation of each year.

fisheries. As a consequence, detailed information regarding impacts on land-based resources during this event are now more readily available.

During the 1982/83 event, flash floods and mud slides destroyed bridges, highways and farmland and killed hundreds of people. The nature, strength, extent and impacts of this event have been well documented in the scientific literature (Barber and Chavez, 1983; Cane, 1983; Halpern et. al., 1983; Lukas et. al., 1984; and Glynn, 1988)[26,27,28,29,30] as well as in popular magazines. Table 2 provides a breakdown of the estimated $2 billion in economic losses suffered by Peru due to the 1982/83 ENSO, based in the reports by CEPAL (1983)[31] and INP (1983).[32] These do not include other societal effects, such as malnutrition and disease, loss of employment and personal belongings, which are difficult to quantify. Social stresses and restoration of the physical infrastructure lasted for many years after the event.

GOVERNMENT RESPONSE TO INTERANNUAL CLIMATE VARIABILITY

Like other disastrous natural phenomena, the occurrence of ENSO's cannot be prevented; societies must adjust to cope with their impacts. Over the centuries, the people of Peru have been forced to endure ENSO-related reductions in agriculture and fisheries production. The strongest events have impacted the nation's capacity to produce food so severely that famine has resulted, along with the associated ills such as malnutrition, disease, etc. Until recently, the Government of Peru has had no option but to "mop up" after the event. For example, the well-documented collapse of the Peruvian anchoveta fishery associated with the 1972/73 event (CPPS, 1987; Glantz, 1990; Jordan, 1991)[33,34,35] resulted in the enactment of governmental decrees regulating further exploitation of the damaged resource. During 1983, the Government reacted in a similar manner. They declared the fishery, agriculture and transportation sectors "in emergency" and followed with a series of decrees and regulations, mostly related to fisheries. Fishing fleets were relocated to other areas, and refitted to target other species such as shrimp. Also, the Government

TABLE 2.
Estimated economic losses (in $ million) due to floods and droughts during the 1982/83 ENSO in Peru

Agribusiness (reduced agricultural and livestock production)	649.0
Fishing (reduced landings)	105.9
Industry (reduced production of consumer goods and oil products)	479.3
Electric Energy (damage to power plants and infrastructure)	16.1
Mining (reduced production)	310.4
Transportation and Communication (damage to infrastructure)	303.1
Housing (damage due to flooding)	70.0
Health (contamination of water, damage to sewage systems, health care centers and hospitals)	57.1
Education (damage to schools)	5.9
TOTAL	1,996.8

undertook a number of unscheduled oceanographic research cruises in order to assess the composition and quantity of coastal marine resources. Furthermore, as a result of the reduced agricultural production, the Government approved increased rice imports. Finally, in an effort to contend with the budget deficit resulting from the disastrous ENSO, the Government issued "Reconstruction Bonds" to be purchased by the population.

In Peru, as in most developing countries in the tropical region, the nature of economic activities is highly sensitive to the variability of climate, particularly in the agriculture sector. Therefore, these countries potentially have the most to gain from an ability to forecast seasonal variations in precipitation, especially as it relates to the growing season. To be useful, any forecast must be accompanied by an effective communication network so that the information will reach the affected communities. After all, a climate forecast has economic value only if it affects Governmental action and societal behavior.

For example, if upcoming precipitation patterns were predicted with reasonable accuracy one to two months before the growing season begins, farmers could be advised with greater confidence on the optimal crop which should be planted for the projected amount of rain and ambient temperature, hence increasing their yields. To a farmer, knowledge of the timing of the onset of the rainy season is critical, as it determines the timing of the planting of his crops. Quantitative forecasts of the amount and temporal distribution of precipitation and the range of ambient temperature during the growing season is important for planning purposes, but more difficult to forecast. Furthermore, in the fisheries sector, a forecast of future physical oceanic conditions in general, and anomalous events like ENSO in particular, would allow for strategic planning and adjustments in fishery practices, which should result in reduced capital losses and reduced unemployment.

Prior to the 1982/83 ENSO event, citizens and policy-makers in the Peruvian agricultural sector were unaware of the availability of climate data, collected outside the region, that could be used in national economic planning and mitigation of impacts of anomalous climate. They became aware of the potential benefits of proper application of available information only after the 1982/83 event, when a series of experimental forecasts were attempted, based on an improved understanding of the dynamics of ENSO.

The example presented here refers to the application of the climate forecast to crop productivity in the northern region of Peru, a region where precipitation and ambient temperature are known to be well correlated with ENSO events (see Figure 2).

In Peru, economic development is based on a set of interrelated national plans for each social and economic sector. The agricultural plan is, by constitutional law, a component of utmost priority within the national economic plan. Its purpose is to promote the efficient development of the sector. It sets forth the basic actions and general goals to be followed by the various public and commercial agencies involved. Specifically, the program establishes annual guidelines and goals for production. The execution of the program is subjected to continuous evaluation which allows for pertinent corrections and for the improvement of the formulation of future plans. The Government, through the Ministry of Agriculture, and the national committees of nongovernmental agrarian organizations together play a critical role in achieving the agricultural production goals, through a consensus-building process. The issues debated include regulation of water distribution in the irrigated areas, prices of fertilizer, interest rates for loans from the agrarian bank and prices of agricultural products. They also discuss the provision of subsidies for particular goods as well as the availability of technical assistance in certain areas.

Once the 1982/83 event ended and the rains ceased (late June 1983) the entire population along the northern coastal region as well as the industries related to agriculture and the agrarian organizations and the Government itself shared a deep concern about what would happen during the subsequent rainy season. Based on knowledge of the behavior of some previous events, there was local speculation that the heavy rains would return late 1983 and early 1984. The need for scientific advice was imperative. Peruvian scientists attempted to explain what had happened and proposed to develop a program to forecast future events. The first task was to forecast the climate conditions for the upcoming rainy season. A network of communication to receive extra-regional climate-related information was set up in September 1983 and analysis of the data began.

The results, based on the analysis of current global ocean-atmosphere observations, indicated that the event would not be repeated in the following rainy season, and were presented early November 1983 to the heads of the agrarian organizations, banking officials, and to the Minister of Agriculture. This information was incorporated into national planning for the 1983-84 agrarian campaign, as well as in the ongoing reconstruction program, and plans of other government and private agencies. The 1983-84 agrarian campaign was a successful one.

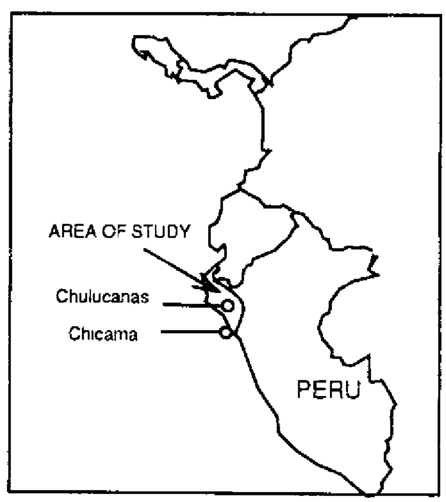

FIG. 2. Location of area of study and observational sites referred to in Figs. 1 and 3.

From this point on, in early November of each year, a forecast of the character of the upcoming rainy season has been incorporated into national planning for the agricultural sector. The scenario can be described as follows: in September of each year, scientists at the Peruvian Geophysical Institute (IGP) analyze the pertinent oceanographic and meteorological data, consult with modelers in the U.S. and elsewhere, and prepare a November forecast based on the current understanding of the evolution of ENSOs and Cold Events, and their impacts to the climate in the northwestern region of Peru. This forecast is presented as one of four possibilities: (i) normal or average condition, (ii) slightly warmer and wetter than normal, (iii) ENSO condition, and (iv) Cold Event - cooler and drier than normal. Once the forecast is made, on behalf of the farming community, the Head of the nongovernmental agrarian organization and Governmental officials meet to arrive at a production strategy. Decisions are made, based on the outlook for the coming rainy season, regarding the appropriate combination of crops to be sown, in order to maximize the yield of the area planted. For example, rice and cotton, which are two of the primary crops sown in the northeastern region, are highly influenced by the quantities and timing of rainfall. For maximum yields, rice needs large

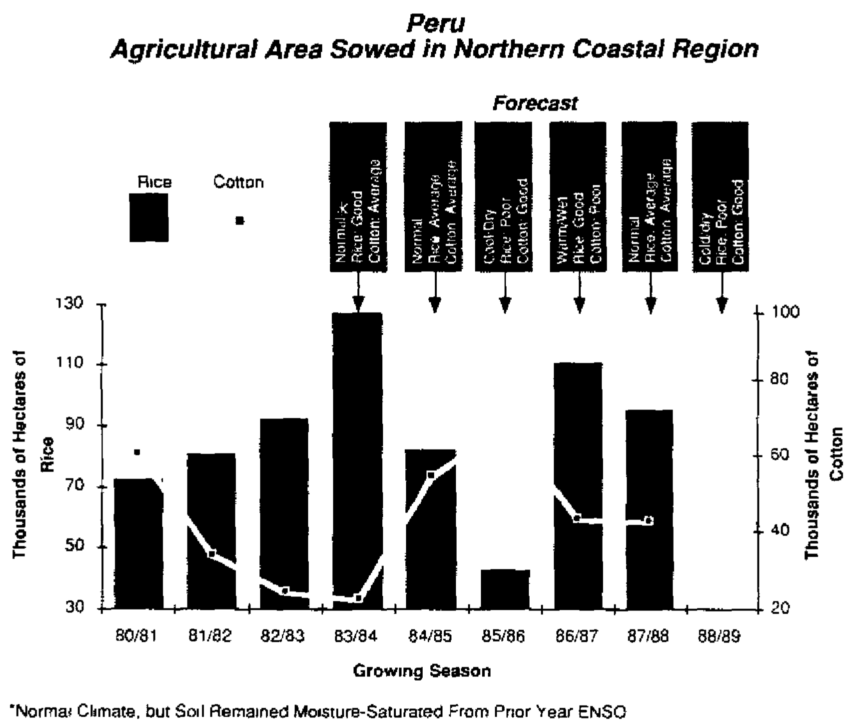

FIG. 3. Pre and post-ENSO 1982-83 agricultural area sowed in the northern coastal region of Peru. Forecast was issued at least one month before the beginning of each crop season

volumes of water and relatively warm ambient temperatures throughout the growing season combined with relatively dry and cooler nighttime temperatures during the ripening phase. Rainfall is, by far, the most limiting climatic constraint to the growth of rice. On the other hand, cotton, with its deeper root structure, is capable of thriving, hence yielding greater production, during years of light precipitation. Once a forecast is made, farmers can chose the optimal combination of crops to sow. Fig. 3 shows the area sowed with rice and cotton in the northern coastal region between 1980 and 1987. Notice the areal increase or decrease depending on the forecast beginning in the 1983-84 growing season.

Of particular interest is the 1987 ENSO forecast. This forecast, issued late September 1986, was based on results of models developed in the U.S. combined with oceanographic and atmospheric data collected in the tropical Pacific. It looked as though an ENSO event of moderate intensity was developing. The information circulated throughout the scientific community as well as throughout Government agencies and even by the popular media. The President of Peru called his experts together, and after much debate he issued an official announcement of the forecast in late December 1986. Again, the forecast was used in the formulation of national agricultural planning and in other sectors, as early as October 1986.

DISCUSSION AND FUTURE DIRECTIONS

Societies learn to conduct daily affairs and economic activity according to the climatic regimes in which they exist, and are often unprepared to adjust as quickly as desirable to dramatic deviations from this expected state. The ENSO phenomenon provides us with an interesting example of how populations are affected by dramatic changes in climate, and how they can organize to react, adjust and (most recently) anticipate and prepare for anomalous behavior.

Future Research

There are a number of tasks remaining as we continue our quest to understand the coupled ocean-atmosphere climate system, and to model and predict its anomalous meteorological manifestations in order to prepare society for its impacts. Recognizing that, the TOGA scientific community plans to undertake a large experiment, the Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) in the western tropical Pacific region, in order to improve our understanding of the physical processes taking place at the ocean-atmosphere interface. This multinational experiment is aimed at understanding the principal processes responsible for the coupling of the ocean and the atmosphere in the western Pacific region (which exhibits the warmest SSTs on earth), the principal atmospheric processes that organize convection in the region, the oceanic response to combined buoyancy and wind stress forcing in the western Pacific, and the multiple-scale interactions that extend the oceanic and atmospheric influence of this warm region to other regions and vice versa. It is anticipated that achievement of these goals will lead to improved simulations of the coupled ocean-atmosphere system, and improved operational capability aimed at the prediction of coupled ocean-atmosphere phenomena such as ENSO and Cold Events on the time scale of months to years (WCRP, 1990).[36]

It should be recognized that although much work remains in improving the predictive skill of coupled General Circulation Models, great progress has been made in making predictions of ENSO as a result of improved understanding of the dynamic ocean and atmospheric systems in the tropics. The TOGA community feels it is time to pursue a more systematic investigation of the predictability of the tropical climate system and to begin planning for routine and regular predictions of the atmospheric and oceanic fields connected with the phases of ENSO. To this end, the TOGA Program on Seasonal to Interannual Prediction is being developed (NOAA, 1991).[37]

Finally, an improved understanding of the climatic teleconnections, or the relationship between the traditional TOGA domain and other regions, is highly desirable. Relationships have been suggested between ENSO and climate variability outside the tropical Pacific region, such as fluctuations in the annual monsoon cycle in the Indian Ocean and Western Pacific region (Shukla and Paulino, 1983),[38] reduced precipitation in northeast Brazil (Moura and Shukla, 1981),[39] Southern Africa (Ogallo, 1987)[40] and the USSR (Pitavranov, 1987),[41] as well as between Cold Events and drought in the north central United States (Trenberth, et al, 1988).[42] Although these anomalous climate patterns have been observed in conjunction with ENSO and Cold Events, the physical atmospheric teleconnections are not well understood. Regional models should be developed to document the effects of ENSO to specific regions, within and outside the tropical Pacific.

ENSO-Related Climate Impacts

Interpretation of the results shown in Fig. 3 is very encouraging in terms of societal responses. As the skill of climate prediction improves, the economic benefit associated with the applicability of this information will increase. The Peruvian experience can provide insights into how societies in other countries might become prepared to benefit from such climate forecasts in the future. In order that individual nations can benefit from ENSO predictions, however, they must have a good understanding of their mean and anomalous climate and precipitation patterns. Nations must organize themselves to benefit from the effort of the global scientific community in providing reliable predictions. This means analysis of existing historical data sets as well as improved systematic data collection efforts. Statistical studies of relationships between regional precipitation patterns and specific ENSO and Cold Events will assist nations in characterizing the differing manifestations of the various ENSO "types".

Socio-Economic Impacts

Predicting ENSOs and understanding the related fluctuations in temperature and precipitation patterns is not enough. Economists and social scientists must be encouraged to join their physical and natural science colleagues in studying the impacts of this phenomenon on society. Unless we have specific evidence on how society will be affected by a particular change in climate, decision-makers will be unprepared to act, either to minimize adverse impacts, or maximize positive impacts. Studies of the economic benefits of societal and governmental responses to climate forecasts should be encouraged.

Public Sector Response

We have established that, in Peru, advanced knowledge of climate conditions can play an important role in the decision-making process, particularly on the use of agricultural lands in order to maximize the yield. It is especially interesting to note the experience during the 1983-84 growing season. Decision-makers were about to act according to their best knowledge as they prepared for the upcoming growing season. Everything they knew was leading them to plan for another ENSO, and sow only the area which would not be damaged by the expected inundation. Scientists came forward and forecasted "normal conditions", and although this was the first attempt to forecast, policy-makers acted on the advice of the scientists and developed a production plan whch resulted in excellent rice crop yields. Thus, a climate forecast—properly applied—made a great difference in the total crop production that year.

Other nations affected by ENSO should be encouraged to formalize a policy-making infrastructure capable of utilizing ENSO forecasts. The experience in Peru which we have provided should be viewed as a model with elements of relevance to each of the interested nations.

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