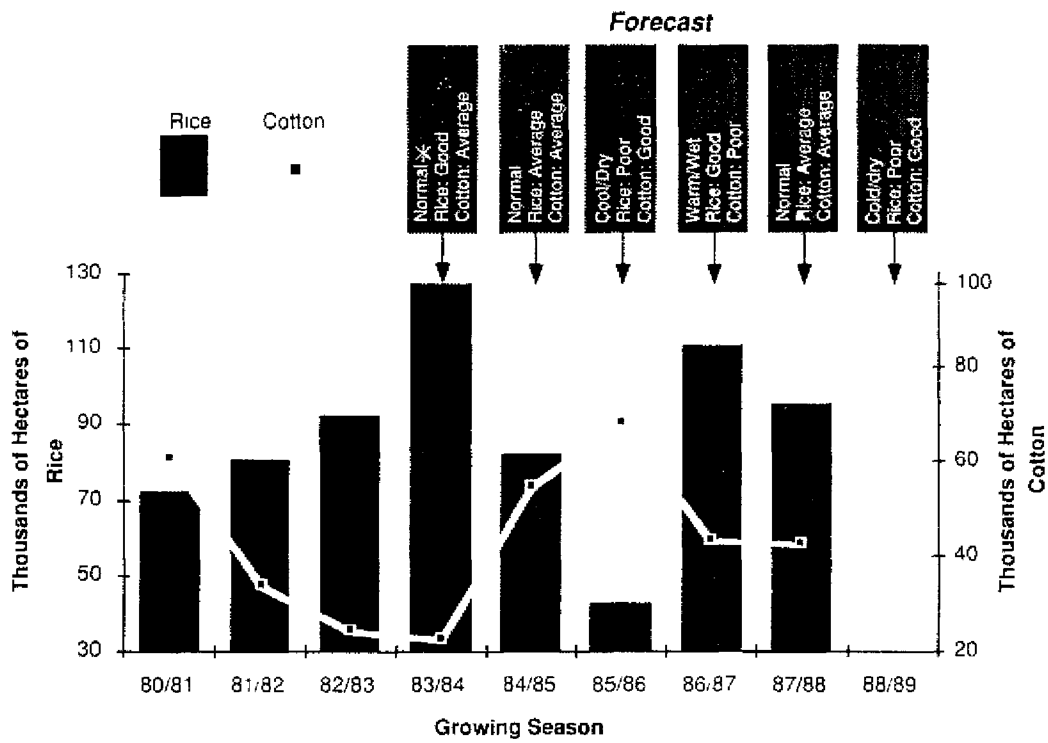
From this point on, in early November of each year, a forecast of the character of the upcoming rainy season has been incorporated into national planning for the agricultural sector. The scenario can be described as follows: in September of each year, scientists at the Peruvian Geophysical Institute (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

Peru
Agricultural Area Sowed in Northern Coastal Region



*Normal Climate, but Soil Remained Moisture-Saturated From Prior Year ENSO

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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