12 "En sus propias palabras..."

Este capítulo presenta algunos pensamientos de investigadores que han estado preocupados del fenómeno El Niño durante las últimas décadas. En cierto sentido es un testimonio de la importancia del fenómeno y de la dedicación de la comunidad científica, en sus intentos por ofrecer a la sociedad información científica que sea potencialmente valiosa para la humanidad.

La intención original fue la de pedirle sólo a unos pocos investigadores, específicamente a aquellos eméritos, que reflexionaran sobre El Niño o sobre algún aspecto de sus carreras asociadas a este fenómeno. Mis invitaciones a participar en este capítulo fueron hechas por teléfono. Cada conversación sobre la investigación de El Niño me impulsó a llamar a "tan sólo un científico más". No transcurrió mucho tiempo para que las pocas contribuciones que yo había solicitado se convirtieran en muchas. La lista habría sido más larga si el espacio lo hubiera permitido.

Los contribuyentes representan diferentes intereses y una diversidad de disciplinas, las ciencias físicas, biológicas y sociales. Ellos también representan una variedad de puntos de vista, algunos conflictivos, sobre las perspectivas de desarrollar una capacidad de predicción de El Niño confiable y creíble, en un futuro cercano. Ellos también sostienen puntos de vista diferentes sobre las causas, como también sobre los impactos de los eventos El Niño. Algunos de ellos se refieren a las interacciones aire-mar en el Pacífico como El Niño. Mientras que otros las llaman ENOS. Algunos hablan de la importancia predominante de las temperaturas de la superficie del mar mientras que otros se centran en la circulación atmosférica. Al respecto, estos párrafos escritos "en sus propias palabras" puede servir como una muestra de la serie de posiciones que existen en la comunidad científica global.

Ninguno de los contribuyentes había leído el resto del manuscrito en el momento que escribieron sus observaciones. Por lo tanto, yo considero que sus comentarios forman parte integral del libro, ya sea que sus puntos de vista refuercen, o complementen, o desafíen algunas veces, los puntos planteados en el texto. No se impuso ninguna restricción a sus párrafos, excepto que ellos debían relacionarse en algún sentido con El Niño.

Nota del traductor: estos comentarios se mantendrán en idioma inglés para no alterar, en modo alguno, la esencia o intención con que fueron escritos.

César Caviedes
Department of Geography, University of Florida, Gainesville, Florida

Being raised and educated in Valparaíso, on the Pacific coast of South America, for me El Niño was a life experience before it became an empirical scientific concept. In my sophomore year in college, El Niño 1975 left a visual imprint in my memories, as I saw thousands of guanays (guano birds) arrive fatigued on the beaches and die of starvation in the Bay of Valparaíso. These images were vivid reflections of a marine-climatological phenomenon about whose technicalities I was to learn several years later reading an enlightening paper by Warren Wooster. For us central Chileans the El Niño years 1957, 1958, or 1965 meant more rains, more dying guanays, less edible fish, regardless of the name of the phenomenon. Axially, nobody, or just a few initiated, new that these were concomitants of an oceanic anomaly that was in full swing off the shores of northern Peru.

Already a trained geographer, and established in North America, the initial impressions that I had of El Niño began to be shrouded in the vestments that science imposes on true-life experiences: my concept of El Niño had to be expressed in sea surface temperature variations, precipitation anomalies expressed as deviations from certain averages, reductions or increases of the baroclinic fields, Southern Oscillation indices, teleconnection figures, and all the other necessary paraphernalia that now go with the El Niño-Southern Oscillation theme. Number crunchers, modelers, and forecasters took precedence over the witnesses of reality: they were more likely to obtain research funds and have their papers published in "reputable" journals.

Perhaps because from early on El Niño meant to me a human experience, I consistently insisted in bringing to light the human implications of El Niño and felt committed to report on the suffering of coastal Pacific duelers when El Niño strikes. Engaged in this task, I was thrilled to discover in 1971 that, when this phenomenon hits the western coast of South America, in northeastern Brazil, on the other side of immense South America, secas (droughts in Portuguese) besiege the rural populations of the sertao (the semi-arid zone). More than any other statistical measure, this discovery of another scourge on the human condition was a revelation of teleconnections at their best!

Working on the human-social aspects of El Niño has been a task not exempted from frustration, particularly when I see the collective inability to capture in objective and accurate traits the negative sequels that this climate-ecological crisis inflicts on humble populations, precisely those who receive most brutally the impact of climate variations.

We have reached a stunning the numerous parameters of ENSO across the planet. Our capacity to predict these oscillations will probably increase with the help of powerful computing tools and intricate programs in the future. But we are incredibly behind properly surveying the social effects dollars in damages that are quotes whenever El Niño strikes hardly reflects the misery, loss of livelihood, and the traumas experienced by the fishermen and oasis farmers of Peru, the llama shepherds of the Altiplano, the agriculturists and riverine dwellers of the Parana River, the jerders of sub-Saharan Africa, or the early 1970s, when El Niño started to become a household concept among the general public in North America, but we are still in a pitifully backward stage in what pertains to studying and trying to solve some of the sociological and human problems caused by this phenomenon. We can only hope that the stunning progress achieved in the scientific aspects of El Niño-Southern Oscillation is also paralleled by major advances in the human-social side of this story before the third millennium begins.

Warren Wooster
School of Marine Affairs, University of Washington, Seattle, Washington

El Niño has grown from a geographical curiosity when I first encountered the phenomenon in 1957 to its present recognition as a major climate signal. Certainly the nature of the physical event is now much better understood, and its reliable prediction in the equatorial Pacific is at hand. But foreseeing the tropical event does not foretell its likely biological consequences, even in the tropics. And whether or not an event will have significant extra-tropical effects, and what they will do, for example, to the return of salmon or to the reproduction of bottom-dwelling fish in high latitudes is even less well known. The atmospheric and oceanic circulation in the high latitudes is surely related to El Niño (or, to be fashionable, ENSO) and so the high latitude biological productivity in the ocean must also be linked. Working out the nature of that linkage, to the point of making useful predictions from tropical events is a fascinating scientific enterprise as well as one with considerable utility. It may also be the key to anticipating the response of marine ecosystems to impending climate change.

George Philander
Atmospheric and Ocean Sciences Program, Department of Geography, Princeton University, Princeton, New Jersey

The El Niño of 1982-83 caught all the experts by surprise. It prompted the rapid development of a capability to predict that phenomenon and, thus, introduced the new era of operational predictions of climate fluctuations. Scientists are now striving to provide routine forecasts, not only of El Niño, but also of global climate fluctuations such as exceptionally harsh winters, persistent droughts and prolonged periods of heavy rainfall. This activity has interesting parallels with operational weather prediction.

L. F. Richardson first proposed in the 1920's that the weather be predicted numerically. He envisioned a room with thousands of people making the necessary calculations. Realization of Richardson's dream became possible after the invention of the electronic computer during World War II. The effort started when the mathematician John von Neumann assembled a small group of atmospheric scientists in Princeton, New Jersey, to use the new computer to forecast the weather, and rapidly blossomed into the mature science of weather prediction whose results are now readily available in newspapers and on radio and television, including a 24 hour channel devoted entirely to weather. To keep the public informed of impending storms and the whereabouts of hurricanes requires a global network of measurement platforms that include polar orbiting and geostationary satellites. Several supercomputers assimilate the data and are essential tools for anticipating weather patterns several days hence. The beauty of this activity is the manner in which it integrates the efforts of scientists with diverse interests including experimentalists who design instruments to measure the atmosphere, and theoreticians who develop models of the atmosphere and also of the oceans and land conditions.

At present, climate forecasting is in its infancy; it is where weather prediction was half a century ago. In retrospect the attempts at weather prediction in the 1050s may seem primitive given the state of computers and of the global measurement network at that time. However, without those efforts, weather prediction would not be as successful as it is today. There will no doubt be criticisms of current efforts to anticipate the next El Niño but without those efforts we are at unlikely to make progress. We are at the beginning of a new era that promises rich rewards.

Klaus Wyrtki
Department of Oceanography, University of Hawaii, Honolulu, Hawaii (emeritus)

Ever since I was a post-doctoral researcher in Kiel, Germany, and observed the wind generation of the seiches [standing waves] in the Baltic, I asked myself the question: do similar sieches occur in the large ocean basins? A study of sea level records in the Pacific finally led me to the conclusion that El Niño was an equatorial Kelvin wave confined to the upper few hundred meters of the ocean. It has been most gratifying to see that my explanation of the dynamics of El Niño as an ocean response forced by the winds has stimulated an enormous amount of subsequent research and the creation of the Tropical Ocean-Global Atmosphere (TOGA) program. This in turn has lead not only to scientific insights into the large-scale ocean-atmosphere interactions, to the development of dynamical models, and to predictive models for El Niño, but most importantly to the establishment of an open-ocean is a basic necessity. Process-oriented experiments, favored by many scientists and the funding agencies, are no substitute for such a global ocean monitoring system.

Early on I participated in efforts to predict El Niño, but soon I became convinced that a prediction of the time of occurrence and of the intensity of the next event will have a high degree of uncertainty, because I strongly believe that the ocean-atmosphere system is an inherently non-linear turbulent system which cannot be deterministically predicted a year or more in advance.

David Enfield
Atlantic Oceanographic and Meteorological Laboratory, Physical Oceanography Division, NOAA, Miami, Florida

As I ponder past progress in understanding ocean-atmosphere interactions and their effects on climate, the most difficult and interesting challenge I see for the near future is how to devise ways of applying that knowledge to benefit global society. How, foe example, can we fashion prediction schemes that tailor physically feasible predictions to the pragmatic everyday needs of people and human economic activity? This involves, among other things, getting very different communities to exchange ideas effectively. How do we that? How can we adapt our present ability to predict sea surface temperatures months in advance to the task of forecasting whether a rainy season will start early or late? How do we tell engineers and insurance underwriters what the future probabilities of strong El Niño events are, years or decades in advance? Climatologists must become statisticians and viceversa; oceanographers must communicate with fisheries experts; vocabularies and jargon must be translated between communities; the general public must be educated; and people of widely differing nationalities and backgrounds must learn to jointly apply themselves to problems that transcend traditional political and disciplinary boundaries. We are only beginning to think about how to do these things. Before they can truly become a reality and impact on society in meaningful ways, the perceptions and consciousness of entire communities must be transformed and an entirely new generation of scientist and decisionmakers must be prepared to carry on with this new paradigm.

Mary Voice
National Climate Centre, Melbourne, Australia

During my career in climate services in Australia, a major hurdle has been jumped by the temperamental thoroughbred named El Niño. El Niño has escaped from the corral of the scientific world and is now running free in the community. Over the past decade, a significant section of the Australian community has heard of El Niño and knows that it is linked to Australian droughts. Many people in climate-sensitive industries have a broad understanding of the Australian consequences of El Niño and also its temperamental behavior. This is a major step forward for a country like Australia, so strongly affected by El Niño.

Like all new theories released into the domain of human communication 8the media, word of mouth, etc.), and like that thoroughbred just over a hurdle, we must now keep its head pointed in the right direction. As scientific communicators, we must ensure that every storm and every seasonal fluctuation not attributed to El Niño through false enthusiasm. We must hold onto the reigns and point our thoroughbred El Niño in the direction of cautious utility for the community, rather than the wild speculation of the racecourse betting ring. This need will increase, as more and more "punters" join in the predictions of the future track record of El Niño.

We are at the barricades of a new race, the horses are in the starter's hands and ready to jump. Our thoroughbred El Niño (perhaps with a name change to ENSO) is the clear favorite for delivering scientifically credible and useful seasonal to interannual climate predictions. The task ahead is exciting: to hold our thoroughbred on track, to call the race accurately so that pundits and watchers alike understand the odds clearly, to manage the fluctuating performance that any thoroughbred will sometimes deliver, and to communicate our knowledge to all so that informed decisions win out over wild speculation.

Gerald Meehl
Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado

One of the genuinely gratifying aspects of studying ENSO is that it has such a rich history. These is some (perhaps bitter?)consolation in knowing that the same things confounding you today, as you try to understand ENSO phenomena, are the very things that confounded Walker, Berlage [Dutch meteorologist], Bjerknes, Troup [Australian meteorologist] and others decades ago. A consequence of this long history is that various features are rediscovered from time to time, for example, the seasonal cycle of ENSO. It does not follow the calendar year, and transitions occurs, often in northern spring and, not surprisingly transitions are the most difficult to forecast. This aspect of ENSO has been known for decades, but has recently come into play as something called the "spring predictability barrier." Modeling studies seem to fail most consistently trying to forecast across the northern spring season.

The challenge and excitement of studying ENSO is that we are simultaneously observing, analyzing, modeling, and trying to forecast ENSO behavior from next season to next century. We can take pride in how far we have come in measuring, understanding, and simulating all of these interactions. But with the likes of Sir Gilbert Walker and Jacob Bjerknes looking over our shoulders, we can also see how far we have yet to go.

John M. Wallace
University of Washington, Seattle, Washington

Much of the progress of the past 20 years in understanding El Niño can be attributed to the advances in our ability to observe the tropical atmosphere-ocean system and to recognize the patterns that we see. Many of us share fond memories of three colleagues who made notable contributions to those advances: Verner Suimi, who invented much of the satellite instrumentation that provides today's global perspective on El Niño; Adrian Gill, whose lucid papers on equatorial ave dynamics expanded and unified our vision of the role of the atmosphere in El Niño, and Stanley

Hayes who pioneered the concept of an operational ocean observing system in support of El Niñ o prediction. *All three of them were dreamers and incurable optimists, whose bold scientific* aspirations have become reality. Were they able to contribute to this volume I am sure that they would be looking forward to even greater achievements as scientists seek to observe, understand, and ultimately predict El Niño, the chaotic pulse of the climate system.

Mike Hall
Office of Global Programs, NOAA, Washington, DC

When scientists began organizing large-scale research efforts to understand El Niño and its relationship to global climate, it became evident that a new school of scientific thought would be needed. The combination of closely interrelated oceanic and atmospheric processes embodied by ENSO in the tropical Pacific required scientific minds not only conversant with, but insightful in, both meteorology and oceanography. Research program mangers believed at the time that this fusion of existing disciplines into something new had to be engendered in large part through management practices. Procedures were adopted to encourage research proposals aimed at the coupled problem, for example.

In *retrospect, it seems far more appropriate acknowledge that nature created the new* discipline of coupled ocean-atmosphere thinkers by placing before us an intellectually seductive problem whose solution demanded, and thus engendered, the evolution of scientific thought across disciplines. Management practices merely followed nature's lead.

Now as we examine the role of ENSO-forced climate variability in human affairs, we see the need for an even broader evolution of thought. In this case, nature compels us to develop a cadre of skilled economic and social scientists intensely interested in the physical system and how it works, and a cadre of expert physical scientists whose excursions into the behavior of human systems are motivated by more than casual curiosity. The two should eventually merge into the new discipline we seek. *Today's pioneers of this new school of thought will be joined by an increasing number of* scientists fascinated by the intellectual challenges which lie at the interface of the two disciplines. Once again a natural evolution of thought will have been driven by an unmistakably important problem.

In building research programs and securing the main resources to design and implement them, we can be confident that nature will provide a clear lead if we are careful to define a workable and relevant problem whose solution requires thinking across disciplines. As always, humans learn when nature teaches.

Timothy P. Barnett
Scripps Institute of Oceanography, La Jolla, California

In the late 1970s, climate research was a poorly thought-of branch of science, and attempts to predict climate were generally looked upon as thoroughly disreputable. So, in 1979-80, when Klaus Hasselmann and I used some fancy statistics to show El Niño events off Peru, we expected to take some heat. No one could shoot us down technically, so they merely dismissed the results. The same methods were used to show that the huge 1982-83 event was predictable a year in advance. At that point, a few science program managers in Washington, DC, began to listen; they saw the prediction ability as justification for future large programs. Indeed, EPOCS and TOGA were based on the promise of predictive skill.

During the mid-1980s, two other groups used dynamical or "hybrid" techniques to advance the results of the earlier statistical studies, which themselves were substantially improved. These very diverse approaches to prediction all said the same thing: moderate to large ENSO events are predictable at lead times of roughly a year or more. These claims, which were again treated with disbelief by many, were backed up by real-time, public forecasts covering the period from 1986 to *the present. Perhaps the most interesting of these forecasts was the call for the first major cold* event in 15 years to occur in 1988. This forecast was made during a talk in the autumn of 1987, at the height of a major warm event. The listen audience was highly skeptical. But the success of that forecast, and the numerous others made since by several methods, leaves little room to doubt our ability to predict big ENSO events. The real questions that remain are (a) "How far in advance can we predict?" and (b) "How can we say in advance that the forecast will be a good (or poor) one?"

Perhaps the most gratifying part of the forecast business our recently demonstrated ability to take the long-range forecast of equatorial Pacific water temperatures and use them to force an atmospheric model, thereby making global climate predictions up to a year in advance, or longer. This approach has shown substantial skill, not only in the tropics, but also over midlatitude regions of North and South America, parts of Asia, and Australia. So, in less than 15 years, we have gone from statistical forecasts of water temperature off Peru (that most folks put no faith in) to a situation where we now routinely make skillful, operational forecasts of global climate with highly sophisticated physical models based solely on our ability to forecast equatorial sea surface temperatures. The latter forecasts are being made today with a variety of statistical and dynamical models.

It has been an exciting ride to have been so closely involved in this rapid advancement, especially since it will have a huge benefit to humankind.

Vernon Kousky
Climate Prediction Center, National Weather Service, NOAA, Washington, DC

Since the 1982-83 ENSO, the most severe ENSO this century, real-time climate monitoring and climate prediction techniques have evolved to the point where reliable one- to three-season forecasts of conditions in the tropical Pacific are routinely being made. These forecasts are being used extensively in regions where ENSO has a significant relationship with precipitation and/or temperature in order to optimize economic planning. Still, much remains to be done in applying ENSO predictions for economic planning purposes and in scientific research on climate prediction techniques. What are the practical limits of predictability for the climate system? Can we develop prediction techniques that will skillfully predict the observed episode-to-episode variability and yield information as to the magnitude of individual episodes? These are just some of the challenges facing scientists as we approach the twenty-first century.

Stephen E. Zebiak
Lamont-Doherty Earth Observatory, Columbia University, New York

El Niño has been a key player in the earth's climatic variability for a very long time, but has only very recently become appreciated in scientific, economic, and social terms. Scientifically, the study of El Niño has led us to a genuinely new understanding of the nature and strength of the interplay between the earth's oceans and atmosphere, and the implications this has for all aspects of climate. The recent advances in predicting El Niño though limited, are exciting, as they pave the way for more applied forecasts that can be put to immediate use in agriculture, water resources, and a myriad of other applications. There is much about climate and its impacts that is not yet understood, but from the study of El Niño it is already possible to foresee new uses of climate information in aspects of human activities that may benefit societies worldwide. It had been, and remains, a pleasure to participate in this research.

Ants Leetmaa
Climate Prediction Center, National Weather Service, NOAA, Washington, DC

We are fortunate to work in a time when nature has given us strong ENSO events (to motivate and provide for our support), a few odd events to provide humility, hard-won observations to limit theoretical speculation, physical models that capture essential real (and imaginary) physics, enough computer power (so we don't have to think too much), to explore new regimes, and good friends to work and compete with. The baby that was born, a fledgling ability to forecast El Niño, is something quite remarkable.

This is not the end, but the beginning of a journey to understand the irregular heartbeats of ever-present climate variability.

J. Shukla
Institute of Global Environment and Society, Calverton, Maryland

El Niño is a good example to illustrate that there is indeed predictability in the midst of chaos. My own interest in the modeling and predictability of El Niño was kindled by a fascinating lecture by Mike Wallace (V. Starr Memorial Lecture at MIT in 1980). El Niño provided the strongest validation of the then-emerging hypothesis that the tropical climate is highly predictable. Although we still have a long way to go in modeling and predicting El Niño with fully coupled ocean-atmosphere models (I do not know of any fully coupled ocean-atmosphere model which has yet predicted an El Niño in real time), the current success with simplified models has already added a new chapter in the history of climate research. The conventional wisdom of the mid-twentieth century that there is no predictability beyond two to three weeks must be modified to recognize that the slowly varying boundary conditions at the earth's surface introduce, at times, a highly predictable component in an otherwise chaotic climate system.

George Kiladis
Environmental Research Laboratories, NOAA, Boulder, Colorado

ENSO research has provided more than just clues to the workings of the ocean-atmosphere system over the tropical Pacific. ENSO is a major recurring natural "experiment" that enables scientists to test their ideas about the physical mechanisms responsible for variability of the global system. The experiment consists of disruptions of the atmosphere during warm and cold events in the Pacific Ocean. Most of the solar energy intercepted by the earth does not heat the atmosphere directly, bit instead evaporates water from the surface of the ocean, which later condenses in clouds, releasing the "latent" heat that was stored as water vapor. In this regard tropical thunderstorm activity can be viewed as the primary "heat engine" responsible for driving atmospheric motions, even as far away as the Polar Regions.

During an ENSO event, the thunderstorm activity is altered in intensity and location and the atmospheric circulation responds by adjusting to the new location of the energy source. Thus, the eastward shift of thunderstorms from Australasia into the central and eastern Pacific during El Niño should have some consequences, such as a stronger jet stream and altered storm track over the North Pacific. Since these expected changes are actually observed to take place, and can also be modelled in computer simulations, this carries much weight in favor of our current "understanding" of how the atmosphere works.

Each new ENSO that is better observed using more advanced technology can provide us with improved data to understand the complicated structure of the climate system. It seems safe to say that ENSO has provided the motivation to improve our understanding of many of the processes in the ocean-atmosphere system that are quite basic and fundamental to the maintenance of the earth's climate itself.

Kevin Trenberth
Climate and Global Dynamics Divisions, National Center for Atmospheric Research, Boulder, Colorado

As a young scientist in New Zealand in the early 1970s, I began exploring sources of the pronounced year-to-year variations in local climate. Analyses of available limited-area data left research questions partly unanswered; the dominant phenomenon proved to be essentially global in scale-the Southern Oscillation. Obtaining global datasets for both the atmosphere and the ocean in order to analyze and understand the El Niño-Southern Oscillation (ENSO) has since been a constant quest. This quest has brought great satisfaction, because various aspects of the phenomenon have been unveiled.

I consider myself very fortunate to have participated throughout the 1985-94 Tropical Ocean-Global Atmosphere program. The great progress in understanding the coupling between the atmosphere and ocean in the tropical Pacific and linkages to weather around the world has brought benefits to society and human activities in many regions. Yet, because ENSO continues to amaze us with its variety of behavior, we must continue to seek to unravel nature's secrets.

Mike McPhaden
Pacific Marine Environmental Laboratory, NOAA, Seattle, Washington

The past decade has seen breathtaking advances in our understanding of, and ability to predict, El Niño-Southern Oscillation events. Two major developments have provided the impetus for these advances. One has been the development of numerical coupled ocean-atmosphere models for studies for year-to-year climate variability. The other has been the development of an ocean observing system for improved description and detection of climate variations. The two have interacted synergistically, with models providing insights into the environmental variables that need to be measured, and the measurements providing data in real time for incorporation into numerical climate forecast models.

As one measure of progress, consider that the 1982-83 El Niño-Southern Oscillation event, the most intense of the century, was neither predicted, nor even detected until near its peak! A little over ten years later, we routinely monitor the pulse of the tropical Pacific (and other tropical oceans) day-by-day from an extensive network of moored and drifting buoys, volunteer observing ships, islands and satellites, and we are making skillful experimental forecast up to one year in advance. The benefits to society of this scientific revolution, though potentially enormous, are just beginning to be realized. The challenge now to maximize these benefits will require the collective effort of environmental scientists, economists, social scientists and policymakers from around the world developing tailored analysis and prediction products for specific regional applications.

Peter R. Gent
Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado

The El Niño- Southern Oscillation is the largest year-to-year feature of the Earth's climate. During the last ten years, this Oscillation has been intensively observed in the Tropical Ocean-Global Atmosphere program. Great progress has been made in modeling this phenomenon, so that predictions of the future evolution of the future evolution of tropical Pacific sea surface temperatures are now being made routinely. Progress, however, has been slower in the understanding of how this oscillation affects the atmosphere away from the tropical Pacific.

In order to capitalize on this understanding, further progress is required on two fronts. The first is continuing the observation, modeling and prediction of the oscillation and its connections to the global atmosphere. The second is to understand how a reliable El Niño-Southern Oscillation forecast can be utilized effectively. This is more straightforward in countries surrounding the tropical Pacific, but less so in countries, such as the USA and Canada, which are more distant and where the oscillation's effects are more varied.

Harry van Loon
Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado

Two points about the Southern Oscillation which were stressed long ago by scientists studying it have influenced me. They are worth repeating.

(a) In 1957, H. P. Berlage of the Royal Netherlands Meteorological Institute came to the conclusion that

> anything useful which was achieved in [inter] season forecasting was arrived at by application of the Southern Oscillation, and furthermore... the Southern Oscillations is

no pseudo-periodic fluctuation, but a physical process of worldwide extent, by which the general circulation in both hydrosphere and atmosphere is accelerated and decelerated rhythmically with a period varying between 2 and 3 years.

(Berlage, 1957, p. 152)

The fact that the cold and warm extremes of the Southern Oscillation are superposed on a two to three year oscillation has been re-demonstrated in the past few years. And it is obvious that any success in interseasonal forecasting over the Indian and Pacific Oceans and the adjoining continents stems principally from persistence in the Southern Oscillation.

(b) **With regard to using the correlations in the Southern Oscillation system for long range forecasting, Sir Gilbert Walker issued the following warning in 1936:**

predictions can only be issued with restraint if public confidence is to be won. The natural consequence is silence, except when the indications are markedly favorable or unfavorable. In a race with 30 starters a conspicuous good horse may, without undue risk, be backed to come within the foremost 6, and we may at first sight seem a confession of weakness to issue no forecast when conditions appear roughly normal; but it is better to admit your limitations, and only speak when you can do so with some safety than to issue predictions when they are little more than guesses.

(Walker, 1936, p.130)

With a little twist this statement holds for public forecasts based on physical models as well. Namely, when you don't know the complete physical structure of the phenomenon and we don't, being constantly surprised by new observations you should restrain yourself to improving your model to such an extent that a public forecast has a fairly high probability of success.

Peter Webster
Department of Atmospheric and Oceanic Studies, University of Colorado, Boulder, Colorado

It is clear that the study of the joint interannual variability of the coupled ocean-atmosphere system has demanded the creation of a new breed of scientist, one who is equally adept in understanding processes in the ocean and in the atmosphere. This is an important change in the paradigm of scientific concentrations that have channeled our thinking for many than merely understanding common vagaries of two spheres instead of one. The amphibian is at the forefront of a revolution in the very fabric of human endeavor and humankind.

For the first time, humankind may have the ability to plan economically, agriculturally, and societally beyond the realms of the annual cycle. The ability to project from a knowledge of the vagaries of ENSO that the summer to come will not merely be warmer than winter (a projection based on knowledge of the annual cycle), but that it will be very much warmer and perhaps even wetter than average, is a formidable tool. Such knowledge releases humankind from a dependence on planning from one year to the next and allows it the freedom of multiyear planning. Just as the knowledge of the annual cycle allowed the development of the agrarian society some 5000 years ago, humankind stands at the edge of the development of an ability to optimize the full range of societal ambitions. Thus, while past research tethered us to the annual cycle, the ability to forecast variability from one year to the next portends a potential that ability to forecast variability from one year to the next portends a potential that is unprecedented. With these advances, however, come new responsibilities. Climatologists must now take into consideration the implications for society of long-term forecasts. For the first time, perhaps, weather scientists have the opportunity to work in parallel with social scientists and planners.

Henry F. Diaz
Environmental Research Laboratories, NOAA, Boulder, Colorado

Great strides have been made in the last 15 years in understanding the El Niño phenomenon. This improved understanding has translated into more accurate and reliable predictions of El Niño occurrences, and of the far-flung influences on the climate in many areas of the world engendered by this quasi-periodic warming of the tropical Pacific Ocean. However, one is reminded of the story of Prometheus and the gift of fire: a tool of great promise to humanity, but one with a sharp double edge! It is vitally important that we learn how to use our improved knowledge wisely.

Antonio Busalacchi
Laboratory for Hydrospheric Processes, NASA/Goddard Space Flight Center, Greenbelt, Maryland

Over the past 30 years, our knowledge of El Niño research has progressed from a relatively obscure phenomenon off the coasts of Ecuador and Peru, to a topical item of discussion at cocktail parties, to a level where experimental forecasts of El Niño and the Southern Oscillation are being used ford the tangible and practical benefits to society in tropical countries that span the globe. The opportunities for an oceanographer or meteorologist to contribute to the entire progression of a particular problem from basic research, to applied research, and ultimately to improvements in the quality of life for humankind are few and far between. It has been a privilege to be associated with this privilege there is also the responsibility to see this line of research through to the point where experimental forecasts of El Niño are sustained and made routine in a manner that benefits both developing and developed countries around the world.

Mark Cane
Lamont-Doherty Earth Observatory, Columbia University, New York

When I started in oceanography, it seemed to me to be very interesting, but essentially useless. So it is a surprise to be where I am now. Skill in predicting ENSO impacts is not very high, but is already at a useful level. Much interesting work remains to translate what we can say about climate variability into usable forms. Ultimately, it may be that aspects of climate are predictable, and that these predictions can be put to some use.

Richard Barber
Duke University Marine Laboratory, Beaufort, North Carolina

El Niño has taught two lessons that will endure, the first is that large-scale variability such as El Niño is not a disaster, anomaly, or cruel twist of fate; it is how Earth works. To mature and live harmoniously in the Earth system, human culture must adapt to Earth's rhythms and use natural variability to its advantage. El Niño is an integral component of the El Niño-Southern Oscillation cycle that determines the character of a large portion of the Pacific Ocean and the meteorological character of much of the world. The El Niño phase of this cycle is required for the non-El Niño phase to exist. The rich fisheries of the eastern boundary of the Pacific, for example, are the products of the cycle. The lean, warm years are the price the Pacific pays for the fat, cool years. Plants and animals of the eastern Pacific are adapted to this variability. After massive El Niño-driven decreases in plankton, fish, birds, and mammals (the world's largest natural biotic abundance cycle), these populations respond with massive reproductive increases. The harmony of this physical-biological oscillation is the first lesson we must take to heart. A side issue biologists will add is that each passage of the cycle exerts awesome natural selection; each El Niño must increase the fitness of the organisms to exploit the variability cycle. No wonder our Coastal Upwelling Ecosystems Analysis (CUEA) program had as a basic tenet the idea that upwelling ecosystems are the evolutionary cauldron that brews more fit species for less variable parts of the world ocean.

The second lesson is a human one. El Niño-Southern Oscillation variability is the first great coupled atmosphere-ocean-biota puzzle that humankind has solved, this knowledge has value in its own right, but as a symbol of what is possible it has greater significance; it tells humans that they can know how Earth works. Extracting this understanding is not easy. It takes many governments with vision and good will, creative individuals sharing their best ideas to reach a common goal, and ordinary bureaucrats, engineers, scientists, and technicians working with selfless dedication and little recognition. Marshaling all those requirements might sound unrealistic today, but in fact that was what happened in the last two decades when the El Niño puzzle was solved.

Colin Ramage
Department of Meteorology, University of Hawaii, Honolulu, Hawaii (emeritus)

Most of us have no trouble recognizing a moderate or strong El Niño with hindsight. It is such a massive and prolonged event that we are hypnotized into believing that it can be predicted. But we tend to forget that every El Niño comprises a collection of individual synoptic events (e.g., warm or cold fronts), that may be favored by preconditions established in the equatorial Pacific, but which are by no means guaranteed by them.

Apparently, a succession of atmospheric surges from the middle latitudes, of preferably the Northern Hemisphere, generates surface eastward-flowing wind surges and, hence, oceanic Kelvin waves in the eastern equatorial Pacific and so cause El Niño. Early surges usually sweep equatorial westerly wind burst, feedback between the equator and higher latitudes may enhance the chance of a succession of surges, but does not guarantee them. Surge frequency probably varies annually, tending to favor El Niño starting early in the year and lasting about a year. Recent observations, however, suggest that (depending on how El Niño is defined) a long enough record would contain starts and stops in any of the months and durations from six months to more then two years. Forecasting El Niño demands that such surges be predicted. I would suggest that success in forecasting El Niño events is slightly more likely than in synoptic (weather) forecasting.

Chester Ropelewski
Climate Prediction Center, National Weather Service, Washington, DC

Society has been interested in seasonal climate prediction since humans first started to depend on agriculture for survival. In recent decades climatologists have come to understand the physical processes and impacts of one important part of the climate system, the El Niño-Southern Oscillation (ENSO). Conceptual models of the physical components of ENSO have formed the basis of numerical computer models. Progress in climate predictions is considered by many scientists to be analogous to that achieved in weather analysis and forecasting. In weather forecasting, the conceptual framework of "frontal" theory early in the twentieth century was followed by the development of experimental numerical forecasts in the 1950s and, in turn, has evolved into the routine multi-day weather forecasts of today. Based on this analogy, potential users of climate forecasts have an expectation of receiving routine, accurate, and useful computer-model- based multi-season climate forecasts in the not optimism is warranted and whether society has finally realized dreams initiated centuries ago.

Stefan Hastenrath
Department of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison, Wisconsin

From the analysis of observations of rainfall anomalies in key tropical regions, an understanding has been reached of the circulation mechanisms that are operative in regional climate anomalies. On this (empirical-diagnostic) basis, methods of climate prediction have been developed for some regions (for example, for Brazil's Nordeste).

The Southern Oscillation (SO) is also reflected in changes of the large-scale atmospheric circulation. It is, then, not surprising that changes of the Southern Oscillation will have some association with variations in rainfall in many regions. However, only a few of these relationships are strong enough to be useful for prediction.

The Pacific El Niño phenomenon occurs during what is considered the low Southern Oscillation phase, due to forcing by the atmosphere. Subsequently, then warm water anomalies, covering much of the tropical Pacific Ocean, feed back on the global atmosphere. In this context, it is noteworthy that in India summer monsoon rainfall is most strongly associated with the phase of the SO in the following, rather than in the preceding, months.

Experiences in tropical climate prediction over the past ten years has revealed a multitude of feasible targets for prediction and a diversity of useful methods. The application of numerical models to climate prediction has concentrated on the Pacific El Niño phenomenon with some success. Widespread publicity, however, may leave the unfortunate impression that this is the only meaningful target and approach. In reality, a broad-based effort is called for, directed to various target regions, combining empirical-diagnostic approaches with numerical modeling methods.

James J. O'Brien
Center for Ocean - Atmosphere Prediction Studies, Florida State University, Tallahassee, Florida

It is a shame that almost everyone blames bad events such as floods, droughts, fish kills and heat waves on El Niño. El Niño is a good dude! When the waters are warmed along the equator from the dateline to Ecuador by 1 deg. C or more above normal for more than five months, the condition is called El Niño. It occurs every three to seven years. The regional climates over all the Pacific Rim countries are affected. For example, major changes occur in fisheries. In the late 1970s, scholars blamed the loss of Peruvian anchovies on El Niño. We now know that the ocean currents along the western coast of South America, during El Niño, go south. The wonderful shrimp along the Ecuadorian coast can be caught off Peru and the Peruvian anchovies can be caught off northern Chile. These countries now take advantage of the El Niño-related climate shifts in the location of various fish populations.

For the southeastern USA, El Niño is wonderful. It brings gentle, extra rain in autumn and winter, which in the dry season suppresses forest fires from Arizona to Florida. In the Atlantic Ocean, the number of hurricanes are suppressed. The probability of two or more hurricanes reaching the USA in a regular year is almost 50%. When El Niño occurs in the winter before the hurricanes will strike the USA.

The opposite of El Niño is El Viejo (the old man) which means water cooler than average by 1 deg.C or more. When equatorial water is cool, there are more forest fires across the southern USA and more hurricanes occur in the Atlantic. The production of winter crops such as oranges are reduced, unless the rain deficit is somehow replaced. Recent published studies have documented that at least $US100 million per year savings can be realized by farmers in timing of planing of planting using reasonably successful El Niño forecasts. It is now possible to predict the onset of strong El Niño events about a year in advance. Unfortunately, we only predict the sea surface temperature along the equator in the tropical Pacific Ocean. Predictions for agriculture, fisheries, forestry, droughts and floods are projected from previous occurrences. In the future, coupled models of the ocean and atmosphere will predict these recurring climate shifts in the Pacific.

Gary D. Sharp
California State University, Monterey Bay, Seaside, California

Despite decades of anecdotal tales and profound public statements about pending events (that never materialize), or of great oceanographers having stomped out of El Niño workshops muttering "there will be no El Niño..." at the onset of the 1982-83 event, claims in the quest for a credible ENSO forecast are routinely forfeited as the tally or "surprises" mounts. There are other atmospheric processes, known and unknown, within which the ENSO cycles are intertwined, such *as an internal oscillation of the earth's atmosphere, called the Quasi-Biennial Oscillation, or QBO.*

Colorado State University atmospheric science Professor William Gray has long pointed out that, as economically devastating as the 1982-83 warm event has proven to be, the ENSO cold phase consequences could make the costs associated with warm events seem trivial. In addition, the benefits of the impacts of the entire ENSO cycle (both warm and cold events) on the periodic revitalization of marine and terrestrial ecosystems has certainly been undervalued.

Environmental science is young. There is not yet a sufficient observational basis for statistical utility. Nor is there much real understanding about the range of normal climate variation, except within the paleoclimate community. We must continue to expand our perceptions as we grow older and wiser. Look upstream, look downstream, high and low...and learn.

William Gray
Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado

The strength and frequency of El Niño events have exhibited variability across several decades. El Niño episodes were more prominent during the first two decades of this century and again since the late 1960s than in the intervening decades, in both of these periods the Sahel region of Africa experienced severe drought conditions, major Atlantic hurricane activity was greatly depressed, and the North-South Atlantic Ocean thermohaline circulation (part of the global ocean's conveyor belt circulation; Figure 12.1) appears to have been weaker than normal.

Gilbert Walker described and defined the Southern Oscillation primarily during what in retrospect was an active era of El Niño activity (1900-1920). But ENSO activity lessened in the 1920s to 1960s in an

Apparent response to a stronger Atlantic Ocean conveyor belt. His pivotal research was largely ignored, until the Atlantic Ocean conveyor belt slowed up in the late 1960s and we began seeing *more frequent and stronger El Niño events. I predict that, when the Atlantic Ocean conveyor* belt speeds up again in coming years, we will once again see a downturn in ENSO strength and frequency and a consequent slackening of interest in ENSO as the primary (or only) seasonal climate determinant. Then we will begin to better appreciate that there are other primary short-term climate "drivers" such as the wind shifts in the stratosphere, extra-tropical Pacific basin features, and so forth, all of which are important climate players.

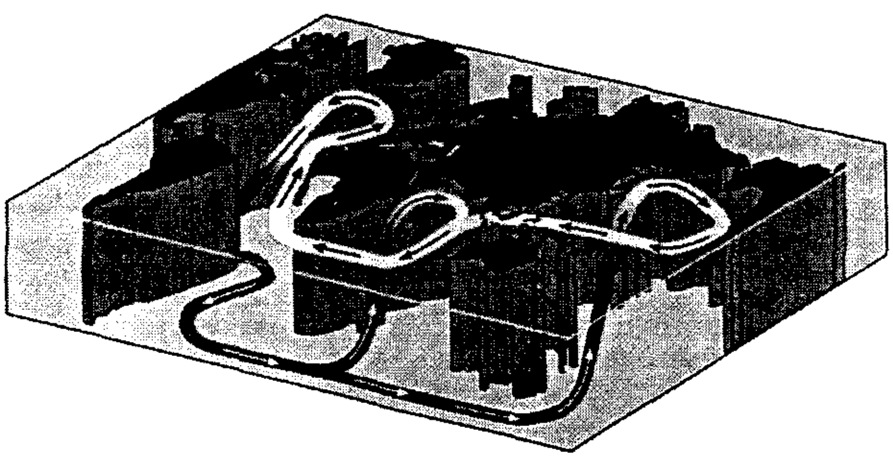

Figure 12.1. The great ocean conveyor belt, depicting global thermohaline circulation. Colder water in the North Atlantic sinks to the deep ocean, to resurface and rewarmed in the Indian and North Pacific oceans. Surface currents carry the warmer stream back again through the Pacific and South Atlantic. This circuit takes almost 1000 years. (From Boecker, 1987, illustration by Joe LeMonnier.)

Richard W. Katz
Environmental and Societal Impacts Group, National Center for Atmospheric Research, Boulder, Colorado

The repercussions of ENSO-related research for other fields are not very well appreciated. For instance, Gilbert Walker's work on the Southern Oscillation and its teleconnections resulted not only in the Walker Circulation being named after him, but also involved an original development in statistics known as the Yule-Walker recursion (a technique employed by Walker to model the quasi-periodic features of the Southern Oscillation). Few are aware that both these labels refer to the same "Walker". Today analogous problems require contributions from disciplines such as statistics, if ENSO forecasts are to realize their potential value to society.

Carlos Nobre
Brazilian Space Research Institute, Sao José dos Campos, Brazil

Undoubtedly the ENSO phenomenon strongly affects the regional climates of South America. Statistical or numerical seasonal prediction of droughts in northeast Brazil of floods in southeastern South America rely heavily on atmospheric and oceanic conditions of the Tropical Pacific. This knowledge has been used by decisionmakers for the benefit of society, as is the case of the use of seasonal forecasts to guide agricultural policies in northeast Brazil with a measurable gain in yields. However, by the same token that no two ENSO. For example, in 1995 subtropical South America east of the Andes Mountains experienced its warmest winter of the last 15 years, and the research community has been forced to look for the causes of such a large and persistent climate anomaly. This has raised some disturbing questions about the actual short-term predictability of the tropical climate.

Pablo Lagos
Peruvian Geophysics Institute, Lima, Peru

During an El Niño event, abnormally warm ocean surface temperatures appear across the equatorial Pacific and along the Peruvian cost, giving rise to anomalous climatic patterns over wide areas of the globe. The floods and droughts that tend to occur during major El Niño episodes are frequently catastrophic.

An improved understanding of the El Niño phenomenon over the past decade has enabled scientists to forecast the onset of El Niño episodes up to a year in advance. Climate, when we can anticipate its behavior, constitutes for the end-users of climate information, a new natural resource that can be used in planning and decisionmaking to increase productivity in the main economic sectors. It is the application of El Niño forecasts that affords society an opportunity to turn scientific information into a useful tool to mitigate its adverse impacts and to undertake efficient socioeconomic planning activities in order to improve the quality of human life.

Neville Nicholls
Bureau of Meteorology Research Centre, Melbourne, Australia

ENSO has short-term effects (such as a drop in crop yields) but also long-term, sometimes permanent effects. Long-term effects arise because of the way that humans react to the short-term climate anomalies caused by an ENSO event. For instance, drop in fish numbers because of an El Niño, combined with overfishing throughout the duration of an El Niño event, could lead to the destruction of a fish population. In Australia, keeping cattle stocking rates at high levels as we go into an ENSO-related drought, can lead to permanent degradation of the grazing lands. However, not restocking quickly when good rains return at the end of the drought can (and has in the past) result in the spread of "woody weeds"; forests of shrubs and small trees replace good grazing land. Even destroying the habitat of indigenous animals or changing the natural fire regime can lead to long-term effects from subsequent El Niño events. Even with perfect predictions of El Niño and El

Niño-related short-term climate fluctuations, it would be difficult to predict and avoid some of these long-term consequences, because of their close dependence on human actions and reactions. The avoidance of such long-term consequences will be a major challenge as we improve our El Niño predictions. And other long-term changes, such as changing global climate, will make this avoidance even harder to achieve than it might be today.

Wang Shao-wu
Department of Geophysics, Beijing University, Beijing, China

I have been working since 1954 in the field of climatic change and long-range weather forecasting. However, the cool summers in 1969,1972, and 1976 changed my research focus. These low temperatures in summer brought tremendous damage to crop yields in northeast China. Michael Glantz and I had a very interesting talk about this more than ten years ago in Nairobi. He mentioned to me the possibility of the linkage between the cool summers and ENSO, sparking my interest in this phenomenon.

During the past ten years, four long climate series have been reconstructed: cool summers in East Asia, the number of landed typhoons in China, the drought/flood index in north China, and finally, ENSO. Each of these time series is about 500 years long, enabling me to study the relationship between variations in climate in China and historical aspects of ENSO. Research on ENSO and its impacts on the climate of China has taken up a great part of my scientific life. I never thought this was a bad choice, and I shall continue this research for the rest of my life.

Eugene Rasmusson
Department of Meteorology, University of Maryland, College Park, Maryland

The story how diverse lines of oceanographic and meteorological research converged to reveal the elegant system of physical and ecological interactions now known as the El Niño-Southern Oscillation (ENSO) phenomenon is a fascinating tale of scientific progress. However, the trail of discoveries that finally led to our current understanding of this important feature of climate variability was long and difficult, over a century in length, with many twists and turns, and not a few dead ends and diversions. I was among the fortunate climate researchers to be "at the right time" in his scientific career to participate in the exhilarating, but often humbling, scientific quest for understanding. This quest followed the general recognitions in the late 1960s of the potential importance of this climate phenomenon for seasonal-to-interannual climate prediction. Time and again during this period, we have felt that "now we understand," only to have Mother Nature reveal a new aspect of this phenomenon which sent us "back to the drawing board".

The last chapters in this story are yet to be written. New discoveries and many surprises are still in store for those who pursue the elusive goal of a full understanding of the ENSO cycle and its application to the prediction of climate variability. For this work we need creative and enthusiastic young scientists who are no more shackled to past explanations than were the earlier heroes of this story, Gilbert Walker and Jacob Bjerknes.