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Michael H. Glantz
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1 Introduction

Climate is what you expect.
Weather is what you get.
(Anon)

If you don't like the weather, wait a few days.
If you don't like the climate, move.
(Anon)

Weather and climate variability

Every year there are extreme climate-related problems around the globe, with droughts occurring in some places and floods, fires or frosts in others. For example, the summer of 1988 was one of a severe drought in the agricultural heartland of North America and extremely low streamflow in the Mississippi River basin. Five years later, in the summer of 1993, a period of very heavy rains led to major flooding along the Upper Mississippi and Lower Missouri rivers and many of their tributaries in the United States Midwest. In the early 1990s, newspaper headlines noted that drought-related food shortages in southern Africa put about 80 million Africans at risk of famine. In August 1992, Hurricane Andrew destroyed southern Florida leaving an estimated US$30 billion in destruction. In early 1995, extreme flooding occurred in western Europe, shaking the confidence of countries such as the Netherlands in their ability to prevent a natural hazard from turning into a national disaster, and challenging their belief that scientific and technological developments had buffered their societies from the consequences of extremely heavy rainfall. This was not unlike the situation in the 1970s and 1980s, when Canadian officials who had sought to "drought-proof" their climate-sensitive agricultural activities in the Prairie Provinces came to realize the impossibility of this daunting task when drought in the region recurred. In 1997–98 the second "El Niño of the century" occurred, only 15 years or so after the first "El Niño of the century".

The point is that record-setting climate events are occurring somewhere

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in the world each year. In fact, Sir John Houghton, who led a major international program that was designed to assess the level of present understanding of the science of climate change (Houghton *et al.*, 1990, 1996), has suggested that records are being set every year and, if there were a year without such an occurrence, that in itself would be record-setting (J. T. Houghton, cited by Greenpeace International, 1994).

Despite the fact that climate fluctuates on seasonal, annual, decadal, and century and longer time scales, in some years there are many more extreme, though not record-setting, meteorological events and more resulting societal problems than one might expect, such as droughts, floods, frosts, fires, ice storms, or blizzards. One such period was 1972–73, when severe droughts occurred in widely dispersed locations such as Australia and Indonesia, Brazil and Central America, India and in parts of sub-Saharan Africa, and heavy flooding occurred in Kenya, southern Brazil, and parts of Ecuador and Peru. At the time it was suggested that some of these widely dispersed climatic extremes might have had a common geographic origin – changes in sea surface temperatures in the tropical Pacific Ocean (El Niño or EN) and changes in atmospheric pressure at sea level across the Pacific basin (the Southern Oscillation or SO). These combined changes have come to be commonly referred to as El Niño events in the popular media and as ENSO (El Niño–Southern Oscillation) events in much of the scientific literature.

Very briefly, an El Niño event can be described as the appearance from time to time of warm sea surface water in the central and eastern Pacific Ocean near the equator. Folklore suggests that the term "El Niño" (literally, the Spanish phrase for "the Christ Child" or "Baby Jesus") was used by Peruvian sailors and fishermen as a label for the annual appearance of warm water along the western coast of their country by December of each year. In some years, the warming along the coast did not dissipate within the usual few months but lingered for more than a year. This too was called "El Niño". In recent decades, the term "El Niño" has been broadened to include all kinds of anomalous sea surface warming in the equatorial Pacific. Scientists now believe that El Niño events are associated with, if not the cause of, many anomalous devastating weather extremes around the globe.

During the past couple of decades the public has learned of El Niño and its impacts in a sporadic way. It would be mentioned in the popular media only when a big El Niño event was believed to be under way. Many of those articles or news releases were simply reports on the events of the day and were devoid of in-depth discussion of the phenomenon. Once the El Niño event (or threat of it) had passed, the media's interest in it waned rapidly. One of the key reasons for undertaking the preparation of this book was to

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provide a user-friendly account of what El Niño is, what it does and why we, as members of different societies and professions, need to have more than a passing, intermittent interest in it, an interest that has been limited for the most part to when it occurs every few years or so. All that has changed in the last few years of the twentieth century.

The intense 1997–98 event has served to heighten interest in El Niño to levels never before seen. There has been an explosion of interest in El Niño among the public and, responding to that, the printed and electronic media have produced a few thousand articles on various aspects of the phenomenon and its impacts.

There has also been an explosion in the number of websites on the Internet devoted to El Niño and now its cold counterpart, La Niña. The problem may have shifted from a situation of too little information on El Niño to one of too much. Now we have a situation in which the reader has to be much more discriminating about the El Niño and La Niña information that he or she finds in the media and especially on the Internet.

El Niño and worldwide climate

The associations or linkages between El Niño events and unusual changes (called anomalies) in normal climate patterns around the globe have been referred to as "teleconnections". These include known, as well as perceived, connections between El Niño events and changes in distant weather or climate-related processes. For example, there appears to be an association between El Niño events and an increased likelihood of droughts in such disparate regions as northeastern Australia, southeastern Africa, Indonesia, the Philippines, northeast Brazil, Central America, and so forth.

One location where ecosystems and human activities are known to bedirectly and, for the most part, adversely affected by El Niño is along the western coast of South America, specifically Ecuador, Peru, and northern Chile. Just about every event, regardless of whether weak or strong, usually has an impact on this region, both on land and in the coastal zone. For example, there is a higher tendency toward torrential rains and flooding during El Niño, in northern Peru and southern Ecuador. Linkages also exist between El Niño events and a below-average number of tropical hurricanes along the east coast of the USA as well as in the location of tropical cyclones off the east coast of Australia, where they tend to shift equatorward by several hundred kilometers. La Niña events, for their part, are associated with an above-average number of hurricanes in the Atlantic and Gulf of Mexico as well as with a westward shift in the tropical cyclone belt in the Pacific.

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El Niño and societal impacts

El Niño is a naturally occurring phenomenon that reappears every few years. To varying degrees, it affects a large portion of the world's population. Potentially useful scientific information about El Niño and its impacts on society will probably go unused, unless there are sustained efforts to educate the public about how to realize the value of seemingly abstract scientific research findings. For this reason alone, it is important for the general public, for managers in various economic sectors, and for policymakers to know more about the El Niño phenomenon, including its teleconnections and their implications for ecosystems and societies around the globe.

The scientific literature and popular media are full of statements about the value to society of being forewarned about the possible onset of an El Niño. On an idealized, abstract level, it is not difficult to find value in forecasts of El Niño events or, for that matter, forecasts of any climate-related environmental change. However, when it comes to a specific El Niño event and its specific impacts in local areas worldwide, it becomes a highly speculative endeavor to place a precise value on such forecasts (Pfaff *et al.*, 1999).

El Niño and Peru

The value to various sectors of Peruvian society of knowing more about El Niño has been mentioned in general statements since at least the end of the 1800s. It is the country that first came up with the name "El Niño" for an oceanic current. Peru, therefore, figures prominently in discussions of El Niño. It was at an International Geographical Congress held in Lima, Peru, in the early 1890s that Peruvian geographer Federico Alfonzo Pezet stated that

> the existence of this counter-current [El Niño] is a known fact, and what is now wanted is that proper and definite studies, surveys, and observations should be undertaken in order to get to the bottom of the question, and find out everything relating to this counter-current, and to the influence which it appears to exercise in the regions where its action is most felt.
> (Pezet, 1895, p. 605)

One of the major regional influences to which Pezet referred was heavy rainfall and flooding in northern Peru that extended well beyond a single season and usually, if not solely, accompanied El Niño events.

At the end of the nineteenth century, one could easily have argued that El Niño was of interest mainly to local populations along the western coast of South America because of the associated disruptions in both normal

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(i.e., expected) rainfall patterns and agricultural productivity and in the reproductive patterns and availability of fish and bird populations along the coast. Actually, concern was directed not so much toward the apparent adverse impacts on fish as it was toward the bird populations which consumed the small fish that dwelled near the ocean's surface and toward changes in coastal navigation and agriculture.

During major El Niño events, the anchoveta fish population was reduced in number because of increased mortality due to decreased food supply in the warm water. Its number also declined because the fish changed their location, becoming less accessible to fish-eating birds. As a direct result of reduced food supply, millions of adult birds and their chicks perished. The carcasses of thousands of dead sea birds washed up onto Peruvian beaches. In many countries, the occasional high level of mortality among bird populations might receive brief notoriety; not so for the sea birds of Peru (Coker, 1920). Various sea birds earned the name of guano birds because they were highly valued in Peru due to their excrement (called guano). Guano was "discovered" by European chemists in the early 1800s to be rich in nitrogen and phosphorus. Guano was considered to be a valuable export commodity for Peru between 1840 and 1880. It was an excellent fertilizer for agricultural fields in Great Britain, Europe, and the USA. El Niño-related reductions in the guano bird population led to a reduced production of guano in Peru's rookeries on the rocky Chincha Islands and along the rocky coastal areas (Figure 1.1).

El Niño and the world

Because of the advent of manufactured fertilizers, along with other trade-related factors, Peru's ability to export guano waned and, as a result, guano-producing birds and guano production were no longer major generators of Peruvian concern about El Niño or its ecological impacts. Interest in El Niño shifted in the 1950s to the exploitation of the anchoveta population for fishmeal production. With the El Niño-related collapse of that fishery in the early 1970s, the health of fish populations in the eastern equatorial Pacific no longer promoted global interest in El Niño episodes. Today, primary concern centers on the realization that El Niño and La Niña are Pacific basin-wide phenomena that can cause regional perturbations of climate- and weather-related processes throughout most of the world.

Increasingly, the task of understanding El Niño is seen by climatologists and meteorologists as an important key to unlocking mysteries about tropical climate and weather patterns and, to a varying extent, about its influence on regions outside the tropics (called the extra-tropics). In fact, an increasing number of El Niño researchers now claim that they can reliably

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Figure 1.1. The rocky islands along the coast of Peru are the nesting sites for "guano" birds. In the absence of an El Niño event, the birds are highly productive, consuming large quantities of fish, primarily anchoveta, that dwell near the ocean's surface. This is converted into guano, bird droppings that are used as a fertilizer for agriculture. When the warm waters appear in the region, signaling an El Niño (warm) event, the fish become fewer in number and are dispersed, becoming inaccessible to the birds. (Photos courtesy of Jaime Jahncke, Instituto del Mar del Peru.)

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forecast the onset of El Niño. Depending on the particular researcher, claims for lead time (i.e., advanced warning) range from 4 to 12 months. Some of these claims are perceived to be realistic and have captured the attention of policymakers who continue to support physical science research on El Niño and El Niño forecasting efforts in a major way. Disruptions of regional climate patterns and of human activities during El Niño reinforce the need for the development of truly reliable long-range climate forecasts, which can then be used by society to reduce the impacts of climate and weather extremes on itself and on vulnerable ecosystems.

El Niño and international science

By the end of the 1990s, scientific research interest in El Niño had blossomed worldwide. El Niño research is no longer left to Peruvian scientists interested in El Niño's local, adverse ecological consequences for sea birds or fish. Now, they have been joined by the equivalent of a small army of scientific researchers, drawn from all continents and from several academic disciplines, which is actively engaged in individual as well as collaborative research on a wide range of El Niño-related topics. Their shared expectation is to resolve lingering mysteries about the phenomenon and to uncover the underlying mechanisms that perpetuate El Niño and La Niña events and govern the phenomena's life cycles. Such discoveries would probably enable scientists to forecast El Niño and La Niña with a high degree of reliability several months in advance of their onset, peak, and decay phases.

Today, policymakers who have been funding science in general are asking questions about the value to society of their research. With limited national budgets, researchers are having to explain to society in more detail the application and usability of their research findings. Forecasting El Niño and, more broadly, forecasting climate variability from one year to the next, has enormous *potential* benefits to society. Some El Niño research findings can already be used to demonstrate how the scientists can produce "usable science". There has also been a sharp increase in policymaker interest in identifying the environmental and societal aspects of El Niño. The scientific community has only recently come to realize the need for sustained efforts to educate the public, especially policymakers, about the societal importance of this phenomenon.

El Niño as a "living" thing

Like many other processes in nature, El Niño comes and goes again and again. Like other recurring phenomena such as seasonal vegetation cycles, mountain snowpack, glacial advance and retreat, and

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sand dune movement, El Niño events wax and wane over time in their responses to global climatic fluctuations.

As with any attempt to discuss a system with many interacting components, identifying the best place to begin is often difficult. For example, how might one best describe the human body? Before discussing the parts of the human body and their functions, one must have an idea of how the body, as a whole, works. By analogy, for El Niño it is necessary to describe the phenomenon (i.e., the body) and then to describe its components and their various interactions. In using such an approach, however, it is difficult to avoid some repetition. This inconvenience aside, the reader will hopefully gain a better picture of El Niño, La Niña, and their impacts on weather and climate anomalies around the globe.

The word "complex"

The scientific community relies heavily on the use of the term "complex". Atmospheric processes are complex; so too are oceanic processes. El Niño is the result of complex interactions between the atmosphere and the ocean. In reality, though, everything is complex, from the electron that circles the nucleus of an atom to the far reaches of the universe. However, in addition to the acceptance of scientific complexity, the term "complex" has also been used for a variety of other reasons. For example, "complex" has been used as an adjective to suggest that an understanding of the phenomenon under investigation cannot be known in its entirety. It has also been used to suggest that it will take a long time (i.e., a great deal of money) to understand it completely. "Complex" has also been used by scientists as a caveat to note "buyer beware"; that the users of such information should treat it as imperfect information. In some instances, it has been used to suggest that you (the reader) cannot possibly understand all that the scientist could tell you about the phenomenon, so he or she will not bother to try.

Thus, the notion of complexity can be used, on the one hand, to expose the limits to our depth of knowledge or, on the other hand, to hide our ignorance. In this book the term will be used sparingly, assuming that readers are well aware of just how complicated various natural processes and interactions are. How much of the science of El Niño does the non-expert *need* to know? How much detail can be left out or generalized in a description of processes and events, while still conveying an understanding that is correct, even if not complete? That is the challenge of those who seek to write about scientific issues for those of us who are not physical scientists.

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Chapter overview

Chapter 2 presents definitions of El Niño, bringing to light a main source of the confusion that surrounds the phenomenon. It attempts to provide a broad definition for El Niño. Chapter 3, entitled "A tale of two histories," presents a brief history of the emergence and spread of scientific interest in El Niño and in the Southern Oscillation.

The fourth chapter, "Biography of El Niño," describes various characteristics and processes associated with El Niño and the Southern Oscillation, while the fifth chapter presents a biography of La Niña. Chapter 6 discusses the 1982–83 event, which until 1997 had been considered the most intense event in a hundred years. Attention is drawn to the true importance of the all-but-forgotten 1972–73 event.

Chapter 7 considers the value, in theory and in practice, of "Forecasting El Niño," providing a few examples of forecast successes and failures. Also mentioned is the unexpected behavior of air–sea interactions in the equatorial Pacific in the 1991–95 period, as well as the need for an international research institute for climate prediction. Chapter 8 begins with an overview (prepared by Michael McPhaden of NOAA's Pacific Marine Environmental Laboratory) of the evolution of the 1997–98 event, and then summarizes the results of a study that assessed the success or failure of 15 forecasts of that event (Barnston *et al.*, 1999).

Many people are interested in changes in air–sea interactions in the equatorial Pacific, insofar as they believe that their regional climate can be affected by events there. To address this issue, Chapter 9 focuses on the linkages of weather or climate anomalies in distant locations that are believed to be associated with ENSO; i.e., teleconnections. The chapter also raises some questions about how global warming of the atmosphere (climate change) might affect El Niño events. Global warming will probably affect the El Niño process in presently unknown ways. Chapter 10 was written by a researcher who was fortunate enough to have been stationed at the Charles Darwin Research Station in the Galapágos Islands and provides a first-hand, on-site overview of the impacts of the 1997–98 event.

How researchers monitor, investigate and forecast El Niño events is briefly discussed in Chapter 11. In the 1996 edition of *Currents of Change*, some of the major post-war international science programs, starting with the International Geophysical Year (1957–58) were identified and discussed.

Chapter 12 focuses on one of the newest areas of interest in El Niño and La Niña research – their impacts on human health. An increasing number of studies have identified strong connections between the outbreaks of various infectious diseases (e.g., malaria, cholera, dengue fever, Rift Valley

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fever) and either extreme warm or cold sea surface temperatures in the tropical Pacific. This chapter underscores the urgent need for a rapid improvement in an understanding of climate–health relationships.

Globally, the media took an interest in the 1997–98 El Niño in part because it had been compared by some scientists at its onset to the devastating 1982–83 event. Chapter 13 introduces a brief account of the media's response to this event from the perspectives of a few countries. Also addressed is the issue of "media hype".

Chapter 14 attempts to identify why each El Niño or La Niña seems to surprise scientists, forecasters and the public. With each successive event, researchers learn more about the phenomenon. At the same time, however, researchers realize that the ENSO puzzle may be bigger than they had originally thought. In Chapter 15, I have identified some key aspects of El Niño and La Niña that I think the general public ought to know.

The final chapter addresses the notion of "usable science" as it applies to ENSO research. It encourages governments worldwide to support both ENSO research and the application of research output to societal needs. A chronology of interest in El Niño and La Niña from the mid-1800s to the end of the twentieth century (prepared by Neville Nicholls of the Australia Bureau of Meteorology and myself) is presented in the Appendix.

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