Report of the Workshop on

ENSO AND CLIMATE CHANGE

Bangkok, Thailand 4-7 November 1991
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PREFACE

The third workshop of the UNEP Working Group on the Socioeconomic Aspects of El Niño—Southern Oscillation (ENSO) met in Bangkok, Thailand, from 4–7 November 1991. The purpose of the workshop was to identify and discuss some of the speculation about ENSO–climate change interactions.

In order to make the report of the workshop on ENSO and Climate Change a user-friendly one, we are adding as a glossary brief explanations of some of the key concepts and processes related to ENSO events.

Making the task of generating public awareness and concern about this recurrent phenomenon somewhat difficult is the fact that the term—El Niño—originally used to describe a regional oceanic current and, later, the seasonal warming of surface waters off the coasts of Peru, Ecuador, and Chile, has recently become attached in many circles to the broader atmospheric-oceanic process known as the Southern Oscillation, thus ENSO. Whereas El Niño, as originally perceived, had been viewed as a regional phenomenon, ENSO is considered a hemispheric or global one. The problem is that the term “El Niño” has entered into the vernacular as interchangeable with “ENSO,” “ENSO event,” or “warm event,” these latter terms being used to describe the larger-scale phenomenon.

This has created some confusion within the scientific community as well as for the media, which must present correct information about this recurring event and its impacts on ecosystems and societies. By the middle of the 1980s, El Niño was on its way to becoming a household word, in the sense that many people were made aware of its existence as a large-scale phenomenon with global teleconnections. This occurred as a result of attention from the popular printed and electronic media following what may have been the largest ENSO event in a century (in 1982–83). Yet, El Niño has become a misnomer when applied to the larger equatorial phenomenon (ENSO) in which scientists have become increasingly interested.
Some scientists use El Niño and ENSO interchangeably. Others use the phrase “warm event” to describe a warming of the surface waters in the central and eastern equatorial Pacific, and “cold event” to denote the opposite phase of the Southern Oscillation. The GLOSSARY which follows is provided to help the reader sort out these concepts.

El Niño is a term originally used to describe the appearance of warm (surface) water from time to time in the eastern equatorial Pacific region along the coasts of Peru and Ecuador. It was once suggested that minor El Niño events occurred about every two to three years and major ones about every eight to 11 years. Today, scientists note that El Niño has a return period of four to five years. When an El Niño event occurs, it often lasts from 12 to 18 months.

La Niña refers to the appearance of colder-than-average sea surface temperatures (SSTs) in the central or eastern equatorial Pacific region (the opposite to conditions during El Niño). Many scientists do not like the use of this term and prefer to call it a cold event (described below).

A warm event refers to the anomalous warming of SSTs in the central and eastern equatorial Pacific. This term is being used to avoid confusion over the use of other terms like ENSO and El Niño. A warming in the regions mentioned is accompanied by a relative cooling in the western equatorial Pacific.

A cold event is one where the SSTs become anomalously colder compared to the long-term average for the central and eastern equatorial region. (It is the opposite of a warm event in that region.) It has been referred to in the past as anti-El Niño and, more recently, as La Niña. La Niña, however, unlike the restrictive view of El Niño, is applied to Pacific basinwide phenomena.

The Southern Oscillation is a see-saw of atmospheric mass (pressure) between the Pacific and Indo-Australian areas. For example, when the pressure is low in the South Pacific high pressure cell and high over Indonesia and Australia, the Pacific trade winds weaken, upwelling of cool water on the Pacific equator and along the Peruvian coast weakens or stops, and SSTs increase in these areas where the upwelling weakens.

The Southern Oscillation Index (SOI) has been developed to monitor the Southern Oscillation using the difference between sea level pressures at Darwin, Australia, and Tahiti, although other stations have sometimes been used. Large negative values of the SOI indicate a warm event, and large positive values indicate a cold event (also referred to as La Niña). It is important to note that there is not a one-to-one correspondence between the occurrence of Southern Oscillation events and El Niño events, using the spatially restrictive original definition of El Niño.
Fig. 1 Five-month running mean of the sea level pressure anomalies at Darwin (dashed) and Tahiti (solid) (from Climate Analysis Center, 1991).

**ENSO** is the term currently used by scientists to describe the full range of the Southern Oscillation that includes both SST increases (a warming) as well as SST decreases (a cooling) when compared to a long-term average. It has sometimes been used by scientists to relate only to the broader view of El Niño or the warm events, the warming of SSTs in the central and eastern equatorial Pacific. The acronym, ENSO, is composed of El Niño–Southern Oscillation, where El Niño is the oceanic component and the Southern Oscillation is the atmospheric component of the phenomenon. The broader definition of El Niño has sometimes been used interchangeably with ENSO, because ENSO is less well known in the popular electronic and printed media.

**Teleconnections** can be defined as atmospheric interactions between widely separated regions. They have been identified through statistical correlations (in space and time). Some of these correlations have been used to generate hypotheses about geophysical processes related to teleconnections. The occurrence of droughts in India and floods in Southeast Brazil during major warm events of the Southern Oscillation are examples of such teleconnections. Most countries in the world are, or should be, interested in this aspect of the Southern Oscillation. Some examples are provided in the following maps.
Fig. 2 Selected extreme temperature events that persisted for a season or longer in the 1982–84 period (WMO, 1984).

Fig. 3 Selected extreme continental precipitation (wet and dry areas) that persisted for a season or longer in the 1982–84 period (WMO, 1984).
Introduction

There has been a growing interest during the past decade about the possible implications of the increased emissions of radiatively active greenhouse gases (GHGs) on atmospheric processes. Most of that interest and attention has focused on the implications for global climate of carbon dioxide emissions and tropical deforestation.

Scientists have generated numerous climate scenarios derived from computer models (general circulation models), some more plausible than others, about the regional consequences of an average global warming of 1.5°–4.5° Celsius resulting from an increase in CO₂ (Houghton et al., 1990). Some scientists in the climate impacts research community have used these scenarios in an attempt to identify possible environmental changes with which future societies might have to cope (e.g., Cohen, 1987). Others have pursued different lines of reasoning in order to gain a glimpse of possible societal responses to climate-related environmental changes. Since most climate model results have described possible changes of mean climate, many of the climate impact studies have used those model results as a point of departure to address possible mean environmental changes due to the increase of CO₂ and trace gases. Few have examined possible changes in extreme weather events, mainly because the model studies usually emphasize changes in the mean climate and not its variability. For example, El Niño–Southern Oscillation (ENSO) events are associated with extreme weather around the globe, but possible changes in important characteristics of these events resulting from a global warming were only briefly discussed in the first Intergovernmental Panel on Climate Change (IPCC) Working Group I Scientific Assessment (Houghton et al., 1990). This is most probably due to the fact that many of the model results used to formulate that report were from equilibrium model simulations with nondynamic oceans. More recently, models used to study a CO₂-induced climate change have included dynamic oceans and several of these models are capable of internally generating ENSO events. Therefore, it appears likely that changes in extreme weather
associated with ENSO may now receive more attention. Here, we have chosen to focus attention on possible changes to climate phenomena associated with these events.

ENSO is an oceanic-atmospheric phenomenon that can affect weather on a global scale. In the tropics the strongest effects often encompass widely scattered regions, from the east coast of the African continent to south and southeast Asia, and across the Pacific Ocean to South America. There is evidence that ENSO can also affect weather patterns in distant parts of the northern hemisphere, as far away from the equatorial Pacific as North America, Russia, and the Ukraine. Because of the large spatial scale of its impacts and because of the lag between early warning indicators of the onset of an ENSO and its actual occurrence, the reliable forecasting of ENSO events some months in advance could prove to be of great value to numerous societies around the globe. Even those societies seemingly not directly affected by ENSO events may find reliable forecasts to be of considerable value by understanding how weather anomalies associated with ENSO affect the agricultural production prospects of their competitors in international and domestic marketplaces.

Because of the high potential value to societies in many regions of the world of forecasting this quasiperiodic phenomenon with some degree of reliability, research on its physical aspects and the societal responses must not only be continued, but increased.

There is, however, a cloud hovering on the horizon for the ENSO forecast community—the uncertainty surrounding the issue of climate change and the alterations in ENSO patterns that might accompany such a change. Today, there is considerable discussion about the possible changes in global climate that might accompany a greenhouse gas-induced global warming of the lower atmosphere. The primary reason for convening this workshop, the third of the UNEP/ESIG Working Group on the Societal Impacts of ENSO Events, is to attempt to identify and assess current speculation about how ENSO phenomena might be altered under the different global heating patterns produced in an atmosphere with increased greenhouse gas concentrations.
The 21 working-group participants were drawn from Australia, Brazil, Chile, China, Indonesia, the Philippines, Thailand, Vietnam and the USA, with representatives from UNEP and the Intergovernmental Oceanographic Commission (IOC). The participants represented several disciplines, reflecting the multidisciplinary nature of the phenomenon and the multisectoral economic interest in ENSO forecasts. The workshop was supported by the World Climate Impacts and Response Strategies Program (WCIRSP) of UNEP and was coordinated and chaired by Michael Glantz, Program Director of the Environmental and Societal Impacts Group (ESIG) at the National Center for Atmospheric Research (NCAR).
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Opening Session

The workshop was opened by Michael Glantz, Director of ESIG (see Appendix for the complete workshop agenda). He underscored the importance of the development of reliable ENSO forecasts for use by countries in both the tropics and extratropics directly affected by ENSO teleconnections. Such forecasts would benefit the economic sector and have implications for human activities within those countries. He noted some positive indications from within the research community concerning the potential for the development of a reliable, user-friendly ENSO forecast some months in advance of the event. He also stressed that, in spite of recent advances in understanding the structure and evolution of ENSO from both observational and modeling perspectives, much is still not understood about the phenomenon. Each participant then presented comments on his/her research activities and interests. Glantz then introduced Mr. Peter Usher, Senior Program Officer for the WCIRSP, who formally opened the workshop.

Coordinator of the Global Environment Monitoring System (GEMS)/Atmosphere Programme, Peter Usher, welcomed participants on behalf of the United Nations Environment Programme (UNEP). He referred to the increasing public attention being given to climate because of potential greenhouse gas-induced climate change. He outlined current international activities related to climate change, including the work of the Intergovernmental Negotiating Committee (INC) to elaborate a framework convention on climate, and that of the UNEP/WMO Intergovernmental Panel on Climate Change (IPCC), which had published its first assessment and was now preparing a supplement to the report identifying new scientific information on climate change and its impacts. Mr. Usher said that the IPCC was encouraging countries to undertake national studies of climate change: compiling inventories of greenhouse gas sources and sinks; impact studies; and economic studies on the benefits and costs of greenhouse gas abatement strategies. UNEP is involved in all these studies and is also assisting the IPCC in the overall coordination of national studies.
Mr. Usher praised the earlier activities and outputs of the ENSO Working Group, particularly its contribution to understanding and anticipating ENSO-induced climate anomalies. [Previous Working Group-related publications include *The Societal Impacts Associated with the 1982-83 Worldwide Climate Anomalies*, (Glantz et al., 1987); *Climate Crisis*, (Glantz et al., 1988); *Teleconnections Linking Worldwide Climate Anomalies*, (Glantz et al., 1991).] He informed the Working Group of the imminent publication of a GEMS library book on El Niño and plans for a television documentary on the phenomenon, should an El Niño event occur in the near future.

Mr. Usher concluded by wishing the Working Group a productive meeting in its examination of the possible relationship between El Niño–Southern Oscillation (ENSO) and climate change which, he said, would fill a significant knowledge gap and would contribute to the work of the IPCC.

Following the UNEP presentation, Glantz made explicit the workshop goals to the participants and presented the issues on the agenda:

- The history of the ENSO phenomenon and teleconnections
- Global modeling and ENSO
- Biological aspects of ENSO
- Examples of ENSO environmental and societal impacts
- Prospects for forecasting ENSO
- Speculation about climate change and ENSO
- Speculation on societal impacts of ENSO changes
- Speculation on status and value of ENSO forecasts

Presentations also included an update by Mr. Usher on the IPCC process and the International Negotiating Committee (INC) activities.
Historical Overview

Neville Nicholls presented a brief overview of the historical scientific interest in the El Niño-Southern Oscillation phenomenon, noting that it extended back to the 1870s, earlier than most researchers realize. Several articles have recently appeared on the history of interest in El Niño or warm events (e.g., Quinn et al., 1987; Hamilton and Garcia, 1986; Glantz, 1984), ENSO (e.g., Brown and Katz, 1991), and teleconnections of ENSO events to worldwide climate anomalies (e.g., Kiladis and Diaz, 1989; Glantz et al., 1991). Today there is great interest in and hope for an improved understanding of air-sea interactions and in applying that understanding to the forecasting of ENSO events and their impacts. There has also been a broadening of awareness and interest in what are referred to as cold events (also called La Niña). These events are roughly the mirror image of ENSO warm events, even as far as their anomalous climate effects are concerned.

Several participants mentioned that cold events were as scientifically and socio-economically important as El Niño and that statistical assessments of both extremes merited considerable research attention. Gary Sharp and George Kiladis pointed out that cold events were also accompanied by an equally strong signal of below-normal surface temperatures and shallow thermoclines over most of the tropics. The La Niña phase can be viewed as a precursor to the El Niño phase. It was noted that no strong cold events had occurred in the period between 1975 and 1988, and that this perhaps led to the lack of interest in their potential impacts. Wang mentioned that his assessment of the Little Ice Age showed that, while there was a decrease in the number of El Niño events, there was no change in the number of La Niña events. All participants agreed that it is important to look at El Niño and La Niña events together, as part of the same phenomenon. A taxonomy of ENSO behavior in all classes of models is being developed to catalog these various modes of behavior (Neelin et al., 1992). Neelin (1991) has also tried to generalize the movement of SST anomalies in the various models in terms of “ocean modes” (SST anomalies move west to east) and “SST modes” (SST anomalies move from east to west).
Rómulo Jordán indicated a need for the scientific community (and our workshop) to distinguish between El Niño and the Southern Oscillation (SO). He stated that they are not the same phenomenon, although Southern Oscillation events include an El Niño component. El Niño itself refers to a warming of the SST off the western coast of South America, and as such is an oceanographic phenomenon. The SO refers to the global-scale atmospheric pressure signal across the tropical Pacific basin. Jordán suggested that the impacts normally described as El Niño are by no means the only consequences of ENSO. He used as an example the 1972–73 El Niño (warm) event during which the impacts on the fish population along the Peruvian coast were devastating to the fishery and the 1982–83 ENSO (warm) event where the impacts in the same region on the fish populations were much less, even though it has been cited as the strongest warm event in one hundred years. Among other factors, the timing of the onsets of the two phenomena is different. Additionally, a warm event always involves positive (warm) SST anomalies in the central equatorial Pacific, but may not always include a large warming along the coast of South America. The latter effect is one of the aspects of El Niño, in the narrowest sense of the definition.

Gary Sharp presented oceanic time series that support the growing view that no two El Niño events have been alike. This view challenges the concept that appeared in the early 1980s of a canonical (or typical) El Niño. Based on composite studies, as, for example, by Rasmusson and Carpenter (1982), it was perceived that El Niño events exhibited similar features with regard to the timing and location of onset. However, later that year (1982) nature challenged this theory by the “unorthodox” (more correctly, unexpected) way in which the 1982–83 warm event developed. This nonregularity raised doubts about the favorable prospects for the reliable prediction of El Niño events.

Nicholls argued that one should view ENSO events as occurring along a continuum. He asserted that there was considerable predictive value associated with the nowcasting of ENSO, e.g., monitoring the current status of ENSO to forecast Australian drought or
ecological impacts. Pablo Lagos noted that the occurrence of strong ENSO events was associated with intense droughts in some locations and heavy rains in others.

In sum, this session's discussions raised some important issues for the natural and social science research communities:

- A clearer distinction may have to be made between El Niño (a local SST warming off the western coast of South America) and ENSO (a hemispheric or global phenomenon).
- Impacts of ENSO events will vary from one location to another because of changes over time in climatic, ecological, and socioeconomic settings.
- There may be several types or even a continuum of ENSO events; this challenges the view that there is one canonical El Niño (or ENSO) type.
- Monitoring the current status of ENSO is valuable for certain kinds of forecasting purposes, despite the existing scientific uncertainties and the lack of forecasting skill with respect to the onset of ENSO.

In the next session Wang Shaowu presented his paper on "El Niño Events, 1470 to 1989," an abstract of which is as follows:

El Niño events for 1470–1989 were identified according to sea surface temperatures (SSTs) over the eastern equatorial Pacific (0–10°S, 90–180°W) and the Southern Oscillation Index (SOI). A chronicle of the El Niño events in the historical time period of interest (1470–1879) was reconstructed using sets of proxy data such as Indian monsoon rainfall, Australian droughts, droughts in Indonesia, Nile floods, Peruvian floods, numbers of landed typhoons in China, cool summers in East Asia, an SOI calculated from tree-ring data, and El Niño events, as identified by Quinn, who based his assessment on meteorological and oceanographical conditions along the coasts of Ecuador and Peru. One hundred and fifteen El Niño events were found, exhibiting a mean return interval of 4.5 years for the period 1470–1989. No close relationship was found between the frequency of El Niño events, and
global warming or solar activity. Finally, strong volcanic eruptions in lower latitudes were followed in most cases by an El Niño event.

Wang also asserted that ENSO was a planetary-scale phenomenon. He noted that he was unable to find a significant statistical correlation between climate change and warm- and cold-event frequency. During discussion of his presentation, concern was raised about the need to use extreme caution in superimposing data sets to identify simple correlations. Bryant Allen also cautioned other participants about the use of historical and cultural information, suggesting that there are many ways in which biases can be introduced into that proxy data (e.g., distortion of memory, cultural biases, etc.). Sharp referred to Roger Anderson’s work (University of New Mexico) which, he noted, strongly suggested the existence of a linkage between ENSO events (as defined by Quinn et al.) and solar activity (Dr. Wang’s assessment, which included many more “events” than defined by Quinn et al., did not find this to be the case).

In his presentation, George Kiladis briefly discussed the history of interest in teleconnections between ENSO events and climate anomalies in distant regions, noting that many of the teleconnections identified by Sir Gilbert Walker in the early decades of the twentieth century had been reconfirmed in the 1980s. He discussed several regions of prominent teleconnections; Northeast Brazil, the Peruvian coastal area, Ethiopian highlands, southern Africa, Indonesia, South Asia and Southeast Asia (Nicholls had already presented the Australian linkages to ENSO). Kiladis noted that teleconnections associated with cold events tend to be opposite to those associated with warm events, for example, anomalously wet areas during warm events tend to become dry during cold events and dry areas tend to become wet.

The issue of possible linkages between ENSO events and volcanic activity was raised once again. Nicholls responded by emphatically asserting that his research activities on this very specific issue could identify no causal predictive relationship between ENSO and
volcanic activities, noting that in the 1982–83 case the ENSO event had been in progress by the time of the El Chichón eruption.

Global Modeling and ENSO

Gerald Meehl presented an overview of modeling activities related to ENSO events. Because we know that ENSO is the product of the dynamical coupling of ocean and atmosphere, the tools that are used at present to study this phenomenon are coupled ocean-atmosphere models. Three main classes of such coupled models can be identified.

- The first class of models uses a limited domain atmosphere coupled to a limited domain ocean. Typically, the domain of this model is the tropical Pacific basin. Such models are relatively simple in formulation and execution, and are thus economical to run on modern supercomputers. One of these models (Zebiak and Cane, 1987) has been suggested by some as a candidate for use as a tool for making operational forecasts of ENSO. A number of other investigators have used this class of models to study the role of internal ocean wave dynamics in producing the ENSO cycle (e.g., Battisti, 1988; Graham and White, 1988; Hirst, 1988; among others). Criticism of this type of model usually centers around the fact that the simplicity and limited domain exclude processes that may be important for ENSO (e.g., the influence of the extratropics).

- A second class of models uses a global atmospheric general circulation model (GCM) coupled to a limited domain ocean GCM (usually the tropical Pacific). Typically, the limited domain ocean is a detailed, high-resolution GCM capable of resolving internal ocean wave dynamics (e.g., Philander et al., 1989; Schopf and Suarez, 1988; Tokioka et al., 1988). Due to the limited domain of the ocean, there may be problems at the boundaries, particularly in the western Pacific.

- A third class of models uses a global atmospheric GCM coupled to a global ocean GCM. This class of models has been developed typically to study the sensitivity of climate to increasing amounts of atmospheric carbon dioxide. Sea ice formulations are
thus also included in the model. To facilitate economical multidecadal integrations necessary for the CO₂/climate problem, these models have, generally, coarse resolution (e.g., 5 degrees latitude by 5 degrees longitude). Because of this constraint, it was somewhat surprising when aspects of ENSO appeared in several of these models (Oregon State—Sperber et al., 1987; NCAR—Meehl, 1990; GFDL—Philander et al., 1989).

Simulations of ENSO with these three classes of models seem to suggest that no one of these models is capturing all aspects of observed events. Some simulate SST anomalies with slight longitudinal propagation and develop ENSO events in the central tropical Pacific (limited domain atmosphere—limited domain ocean). Others simulate warm-event SST anomalies that propagate slowly eastward to become established in the central equatorial Pacific (global atmosphere—limited domain ocean). Still others produce warm SST anomalies that appear off the coast of South America and move westward to the central equatorial Pacific (global atmosphere—global ocean). Since observed ENSO events exhibit all of these aspects of ENSO evolution in various combinations, it is likely that each class of model is simulating a subset of the total ENSO phenomenon. Yet, even though all classes of models evolve toward ENSO differently, all culminate in an “event” in the central tropical Pacific (i.e., with warm SST anomalies occurring there).

Since most of this modeling activity is relatively recent and all the models have significant limitations, their use and/or application for forecasting or for societal impacts research purposes is a topic of much debate in the research community; in particular, whether these models should be used (1) to make operational seasonal ENSO forecasts, or (2) to provide estimates of how ENSO may be affected by an increase of atmospheric CO₂ and other radiatively active trace gases are issues that are widely discussed by modelers as well as policymakers. Clearly, these fairly new research tools will undergo rapid improvement during the next few years, and results related to seasonal forecasts and climate sensitivity must be viewed in the context of the systematic errors contained within
the present models. Meehl emphasized that this type of global circulation modeling was a relatively recent activity and that care should be taken by those who seek to use their output for decisionmaking purposes.

Biological Aspects of ENSO

With regard to the biological aspects of El Niño and of the broader ENSO events, Sharp asserted that ecological systems are tightly linked to day and night durations; light intensity and quality; hydrologic patterns; local temperature patterns; and sequences of these with regard to nutrient availability. The seasonal cycle is the single, fundamental climatic patterns to which flora and fauna are attuned, as evidenced by physiological characteristics of species and by their associations as used to define zoogeographic provinces. The most frequent recurrent climatic perturbation is ENSO. As such, it is important to distinguish between changing seasonal patterns in response to changes in ENSO and those resulting from a greenhouse-gas-induced climate change. He argued that where El Niño research would prove to be most valuable was in defining El Niño and forecasting local and regional perturbations of the seasonal cycle. He suggested that climate change would also manifest itself primarily as changes in the local and regional characteristics of seasonality. He then proposed that the entire Western coastline of the Americas (North, Central and South) provided researchers with a unique linear gradient of ocean and terrestrial responses exhibiting symmetry about the climate equator. Sharp also provided examples of ENSO-like events off the coast of southern Africa (referring to them as Benguela Current El Niño events). Some of these events derive from Atlantic equatorial sources and propagate southward. Other warming events clearly propagate from the Indian Ocean.
Examples of ENSO-related Environmental and Societal Impacts

This session centered on country and regional impact assessments. A key point that emerged from almost all of the cases presented centered on human aspects of land use. More specifically, human activities such as deforestation and other forms of land clearing have rendered societies more vulnerable to the impacts of ENSO events. J.R.E. Harger cited the fires that recently occurred (as in 1982–83) in Kalimantan. He suggested that secondary forest growth (following initial deforestation) is more likely to be destroyed by wildfires, given their shallow roots. While these fires may be blamed on ENSO events, human activities must also share the blame for their occurrence. Allen reinforced Harger’s view and asserted that the sequence and, therefore, combination of wet and dry years is of great importance in determining the impacts of an ENSO event in, for example, the Papua/New Guinea region. He also noted that demographic changes and the expansion of human activities, such as agricultural cultivation up along hillsides, has also increased the vulnerability of societies to ENSO impacts, regardless of whether those events become more or less frequent and more or less intense because of a change in the global climate.

ENSO Forecasting

Kiladis opened the morning session by leading a general discussion of ENSO teleconnections. He emphasized the fact that climatic anomalies associated with La Niña are almost universally opposite in sign to those associated with ENSO warming. Thus, regions such as India, Australasia, and Central America often experience flood conditions during La Niña (cold events), which can have as adverse an impact as droughts over these areas during warm events. Also discussed was the tendency for warm-event years to occur adjacent to cold events, such that the ocean–atmosphere system appears to go from one extreme state in one year to the opposite state in the following year. Though by no means regular, this “biennial tendency” can exacerbate the impact of ENSO, such as when severe erosion due to heavy rains follows a year of fire and drought in a tropical forest. It must
also be kept in perspective that ENSO warm events are experienced in other areas, e.g., New Zealand, as cool, wet periods.

Along with the tendency for drought conditions over a large portion of tropical land areas, ENSO is generally defined by above-normal temperatures in the tropics. This has the effect of increasing evaporation, further amplifying the desiccating impact of low rainfall. The tropical warming signal is in fact observed over the extra-equatorial oceans as well and can lag the warming of the eastern equatorial Pacific by three to six months. A discussion of the possible causes of the zonally symmetric tropical temperature signal concluded that, while the local warming of the eastern equatorial Pacific was due to a decrease in oceanic upwelling, the remote warming over the rest of the tropics was likely due to an increase in radiation associated with reduced cloudiness.

Pablo Lagos raised his concern about the use of the terminology Year 0, Year 1 and Year –1. He suggested that Year 0 for ENSO may not be Year 0 for El Niño. Year 0 for El Niño corresponds to the year in which the January–March anomalies appear first, and therefore Year 0 for the 1982–83 and 1986–87 events are 1983 and 1987. That ENSO (warm) event began in September/October 1986, later than “normal.” He felt that this would have been recorded as if 1987 were Year 0. Thus, a list of Year 0 for El Niño would differ from a similar list for ENSO. From a meteorological applications perspective, Lagos noted the importance of identifying the target audience for an El Niño or ENSO-related forecast: for example, to farmers, rainfall and summer temperatures are most important, whereas to the fishing industry, SSTs are most important.

Nicholls discussed how to use ENSO information without having to make formal ENSO predictions. He noted that there were two important types of predictions: (1) predicting the onset of ENSO (warm event) and (2) using the onset of the ENSO event to predict ENSO-related climate anomalies or ENSO-related societal impacts. He suggested that the climate impacts research community should not overfocus on prediction of the ENSO onset, because there is little skill as yet associated with that forecast. Despite current
attempts to improve ENSO forecast skill, there are mixed views about the prospects for the development of a reliable, credible operational forecast of the onset of ENSO in the near term.

However, once the beginning of an ENSO event is identified, the skill to forecast related impacts increases markedly. He asserted that climatic patterns imposed by ENSO can be used to "explain" many features of the natural environment. There is useful, reliable information regarding climate anomalies associated with the early as well as later stages of both cold and warm events. Nicholls gave several examples from Australia illustrating that once the onset of a warm event is known, its known climate impacts could be used to influence land use and crop management plans, even if the onset of the event could not be predicted.

Harold Brookfield and Bryant Allen asserted once again that knowledge about the sequencing of wet and dry years can provide extremely important and useful information for agricultural planning and production activities, as well as preparing for and mitigating adverse impacts. They reminded participants that famines often develop in the absence of ENSO-related climate anomalies (e.g., droughts in the Indonesia–Papua New Guinea region), noting that they are due as much to socioeconomic and political factors (e.g., Sen, 1981) as to air–sea interaction in the tropical Indian and Pacific Oceans. Interannual climate variability occurring on top of prevailing socioeconomic conditions determine the likelihood of severe food production and availability problems at any given point in time. The importance of the fact that changes in land-use patterns in marginal areas set the stage for societal disasters when ENSO events occur was re-emphasized. In other words, population movements into marginal areas increase the risk of climate-related hazards, even without a change in climatic conditions.
Speculations about Climate Change and ENSO

Nicholls posed a list of questions about what is known about the possible impacts of climate change on ENSO. The approaches and evidence addressed were as follows: (a) theory; (b) low-order coupled models; (c) historical observations and evidence; (d) historical documentary evidence; (e) paleo- and proxy evidence; and (f) other (evolutionary/adaptation) evidence. Each of these factors was discussed at length and is briefly summarized.

What do we need to know about ENSO and climate change?

1. Will ENSO continue to occur?

   Likely. Proxy climate evidence indicates that ENSO has continued to occur in a variety of different climate regimes, both warmer and colder. There is little evidence that ENSO has been “stuck” in one extreme.

2. Will ENSO be more intense?

   Possibly. Global coupled GCM results suggest an intensification of ENSO climate effects in the tropics, with anomalously wet areas becoming wetter, and dry areas drier.

3. Will ENSO change in frequency?

   Possibly. A low order coupled model indicates that changes in upper ocean heat content associated with global warming could affect frequency of occurrence of ENSO.

4. Will ENSO change in duration?

   Less likely. Present-day events exhibit a biennial tendency linked to the annual cycle. However, single and multiyear events have occurred in the past, and there is no evidence to indicate a change in this characteristic. This also implies that the mechanisms involved with transition from a warm to cold phase (i.e., El Niño to La Niña), and vice versa, would remain similar.

5. Will there be a change in tropical teleconnections?

   Unclear. A global coupled model suggests that similar teleconnection patterns to those of today would occur in the tropics with an increase of CO₂ in the atmosphere.
6. Will there be a systematic change in extratropical teleconnections?

Likely. Prior modeling work on extratropical teleconnections and changed climate basic states suggests that a large mean climate change associated with an increase of CO$_2$ and trace gases would result in altered extratropical teleconnections. Results from a global coupled model with increased CO$_2$ are consistent with this earlier work. Based on analyses of records of the past 100 years or so, these teleconnections have held.

7. If changes do occur, will there be changes in both warm and cold events?

Likely. Changes in upper ocean thermal structure are likely to affect both warm and cold extremes of the oscillation. Associated changes of sea surface temperature and convection have implications for effects on the monsoons and typhoon activity.

Discussion took place on the Cane/Zebiak model and on GCM-coupled modeling activities. Meehl described recent GCM experiments (co-authored with Warren Washington and G. Branstator, 1992). Their findings suggested that with a CO$_2$-induced climate change, the climate effects in the tropics associated with ENSO events would become more intense, with anomalously wet areas becoming wetter and dry areas becoming drier. He also noted that, according to his GCM model runs, there would be a change in extratropical teleconnection patterns, with more zonal anomalies of sea level pressure (SLP) than seen in present-day events. This change in SLP teleconnection patterns would have implications for changes in regions of anomalously warm and cold conditions in the extratropics associated with ENSO.

There is no evidence that suggests that the occurrence of ENSO events stopped at any time during the past 500 years. Wang Shaowu noted that in his 500-year proxy data record, he was unable to find a pattern with respect to changes between warm periods and cold periods. It was also noted that coral bleaching, the rate of which is affected by ENSO, shows no real changes in the past 1000 years. Nicholls suggested that natural flora and fauna had adapted to ENSO variability over the past 20,000 years.
Speculation on Societal Impacts of ENSO Changes

There was considerable discussion about changes in human activities and in the location of those activities that can exacerbate the consequences of ENSO events on the natural and human environment. Human activities that were specifically cited in this context included the destruction of mangroves, the reduction in forest cover, and the movement of people into marginal areas for food production and human habitation. Glantz referred to this process as one in which “drought follows the plow.” Societies, it was suggested, are less concerned about mean climatic conditions than about climate variability. The participants supported the view that climate variability and extreme events cause problems for decisionmakers at all levels of social organization, from local to national.

Speculation on the Status and Value of ENSO Forecasts

Harger and Lagos noted the important, but often neglected, role of the media’s influence with respect to climate-related issues on political decisionmakers. The participants agreed that there was an urgent need to educate both groups on the meaning and potential value of an ENSO forecast. It was also noted that an ENSO forecast was just a forecast and not a guarantee of occurrence. Concern was raised about whose ENSO forecast should the user community believe, as each year there are different groups issuing forecasts about either warm or cold events. Such conflicts in the forecast area confuse the public, policymakers, and the media. An unresolved question on this issue was whether there might be some way to organize, coordinate, or calibrate these forecasts more rationally than at present. More attention must be paid to this aspect of ENSO forecasting, in order to enable societies to reap optimal benefits from ENSO forecasts. However, it was noted that reputable individuals and groups who presently perform ENSO forecasting exercises do so in an experimental mode. This is a reflection of the fact that empirical knowledge and model simulations of ENSO are far from the level of providing operational forecasts.
Summary Session

Based on the discussions of the previous three days, Glantz presented a set of statements about what is known about the societal aspects of ENSO events. These statements were actively discussed. The revised statements are as follows:

1. Societies around the globe have been critically affected for thousands of years by the environmental changes associated with ENSO events.

2. Climate extremes and the relatively sudden reversal from one extreme to another associated with ENSO are known to alter most human activities (food production, fisheries, water resources) in the areas affected. These extremes also impact the infrastructure supporting those activities such as energy production, transportation and human settlements.

3. Societies are affected not only by single ENSO events but by the combination of characteristics of a set of such events over time (their severity, frequency, duration, and location).

4. Judicious use of ENSO information can provide societies with leverage against their adverse consequences and take advantage of the positive aspects of ENSO events. While these events cannot be stopped, their impacts can be prepared for and timely information of their occurrences and consequences can be instrumental in the establishment of successful coping mechanisms.

5. Two converging factors, however, can change existing relationships (and current wisdom) about society–ENSO–environment interactions: demographic changes and climatic changes.

6. Deforestation, settlement of areas marginal for the sustainability of human settlements, and inappropriate development activities have rendered societies more vulnerable to the impact of ENSO events, whether or not climate change will alter the pattern of ENSO events.

7. Changing land use patterns, human settlement needs, the transfer of inappropriate technologies, and a lack of insight and understanding of the limits of sustainability of regions can (and have) adversely affected (a) coping mechanisms and (b) the severity and (c) the location of harmful impacts of ENSO-related climate anomalies.

8. Changes in the characteristics of ENSO-related processes are now expected, as the climate changes, but in ways presently not fully understood. This issue is just beginning to be addressed by the climate modeling community.
9. There is a need for better interaction between the ENSO, natural and social science research communities for improved understanding of changes in interactions between ENSO and demographic processes.

10. There is a need to consolidate, pool and analyze results of socioeconomic research in the area of ENSO impacts.

11. The ENSO research community must produce output useful to decisionmakers in governance, development planning, hazard reduction and resource management.

12. Formal institutional arrangements should be made to ensure that research on the society–ENSO–environment interactions be integrated and widely disseminated.

It was noted that:

- the IPCC scientific assessment paid only brief attention to the ENSO phenomenon, and that this omission needed to be brought to the IPCC’s attention.

- A focus on global change must be balanced by a concern for the impacts of existing extreme meteorological events (i.e., climate variability) and impacts especially in the tropical regions.

- There is a strong need now for support for research that bridges the physical, biological and social science aspects of ENSO.

- There is a need to encourage the development of an ENSO-related network in those countries directly affected by ENSO events.

- Even though we know that a global climate change is in the offing, the impacts of ENSO are likely to be much greater over the next 50 years than the impacts of global warming. Moreover, a global warming will possibly exacerbate the societal impacts of ENSO events.
REFERENCES


APPENDIX
List of participants

Workshop on
ENSO EVENTS AND CLIMATE CHANGE
4-7 November 1991
Tara Hotel, Bangkok, Thailand

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ENSO/Climate Change Workshop
4–7 November 1991
Tara Hotel, Bangkok, Thailand

Sunday, 3 November 1991
7:00–9:00 Informal reception at hotel

Monday, 4 November 1991

Introduction to workshop
9:15–10:00 Welcome to meeting (Glantz, Usher, Thai official(s))
   Introduction of participants (affiliation, interests, etc.)
10:00–10:30 Break

Introduction to ENSO
10:30–11:00 ENSO: history of concept, phenomenon, interest, teleconnections

Update on ENSO research
11:00–11:30 Observational aspects
11:30–12:00 Discussion
12:00–1:30 Lunch
1:30–2:00 Modeling aspects
2:00–2:30 Biological sciences component
2:30–2:45 Discussion
2:45–3:00 Break

Societal aspects and impact assessment methods
3:00–5:00 Presentation/discussion of assessment methods and case studies

Tuesday, 5 November 1991

Prospects of forecasting
8:30–9:45 Teleconnections (tropical and extra tropical)
9:45–10:15 Break
10:15–11:00 On forecasting ENSO: What we can do, what we can’t do – the scientific perspective
11:00–12:00 On forecasting ENSO: What we can do, what we can’t do – the societal perspective
12:00–1:30 Lunch
1:30– OPEN
8:00–10:00 Informal evening forum: IPCC update

Wednesday, 6 November 1991

ENSO and climate change
8:30–10:00 Current speculation about impacts of climate change on ENSO
10:15–10:30 Break
10:30–12:00 Speculation on societal impacts of changes in ENSO
12:00–1:30 Lunch
1:30–2:15 What we know about climate change and ENSO
2:15–3:00 What we need to know about climate change and ENSO
3:00–3:30 Break
3:30–4:15 What research is needed? By which organizations?
4:15–5:00 Discussion of workshop statement on climate change and ENSO.
7:30– Group dinner

Thursday, 7 November 1991

9:00–10:00 Presentation and discussion of workshop statement on “Climate Change and ENSO”
10:15–10:45 Break
10:45–11:30 Revision of workshop statement. Publication possibilities?
11:30–12:15 Where do we go from here?
12:15–1:30 Lunch