understand the basis of the global scale of meteorological processes. Studies led by Sir Gilbert Walker, the second Director-General of British Observatories in India, demonstrated that a correlation existed between surface air pressures over the Indo-Australian region and those over the eastern South Pacific Ocean and South America. In particular, failures of the Indian summer monsoon were associated with higher than normal surface air pressure extending from India to Australia; at the same time surface air pressure over the eastern South Pacific Ocean was generally lower than normal. Strong monsoons were associated with lower than normal surface air pressure over the tropical region from India to Australia and higher than normal surface air pressure over the eastern South Pacific Ocean. Walker, in 1909, referred to the relationship between monsoon intensity and the cross-Pacific Ocean surface pressure patterns as the Southern Oscillation.

Walker also noted that the monsoons of India and South East Asia have their origins in warm moist air generated over the northern Indian and Pacific Oceans. A major overturning atmospheric circulation along the equator, with easterly Trade Winds feeding rising air in the rain-producing clouds over Asia and returning westward at high levels to sink over the eastern Pacific Ocean, is known as the Walker circulation in recognition of this work. Periods of drought over India and South East Asia are associated with weakening of the Walker circulation.

It was not until the 1960s that a linkage between the Southern Oscillation and the El Niño began to be formed. The International Geophysical Year (IGY) of 1957–58 was a stimulus for international cooperation in observations and multidisciplinary studies. In particular, it was a stimulus for studying the interactions between the atmosphere and the oceans that led to knowledge of the important role of the oceans in modifying seasonal climate.

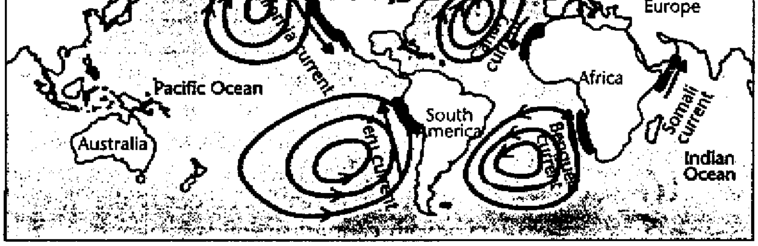

Figure 2
Major coastal upwelling regions of the world and the sea level atmospheric pressure systems that influence them.
(Glantz *et al.*, 1987)

El Niño was originally a phenomenon of the coastal waters of northwestern South America. The cold northward flowing Peruvian current, also known as the Humbolt current, has a marked seasonal cycle in tropical latitudes. The prevailing offshore south-easterly winds cause upwelling in the waters of the coastal zone for most of the year and bring high nutrient levels in the surface layers. The coastal waters support abundant fish stocks that in early times provided an important food source for the coastal communities that have traditionally benefited from the rich offshore marine resources. Since the 1950s significant export industries have become established to commercially exploit the seemingly abundant fish stocks.

El Niño was originally the name given by local fishermen to the annual appearance of a warm southward flowing current in the surface waters off coastal Ecuador and Peru in the Southern Hemisphere summer. The first appearance of the warm waters was at about the time of Christmas, the time associated by Christians with the infant Jesus (Spanish: El Niño — the boy child). The recurring annual warming of the coastal waters has been observed for centuries by people along this coastline and is associated with a seasonal dispersal of fish stocks and low catches.

The coastal communities also recognized that in some years the cold nutrient-rich waters failed to return during the following year, giving a poor fish harvest and with disastrous consequences on local food stocks and community welfare. It is now recognized that these periods also probably involved abnormal and prolonged warming of the eastern equatorial Pacific Ocean. These prolonged periods of abnormal warming are now generally referred to as El Niño events. However, it was not until the mid-1960s that the El Niño phenomenon was recognized as more than local significance. Several scientists drew attention to potential linkages between the El Niño of the eastern equatorial Pacific Ocean and the Southern Oscillation that affected weather patterns across the tropical Pacific Ocean.

By the late 1960s Peru was a major fishing nation supplying international markets with fish meal, an animal feed supplement. The 1972–73 El Niño was devastating for the Peruvian fishing industry and the Peruvian economy. The failure of the anchovy fishery to return to the high pre-El Niño levels of productivity became a focus of international concern during the mid-1970s. Studies of the 1972–73 El Niño event drew attention to the major changes to the surface waters of the central and eastern Pacific Ocean and their linkage to contemporaneous climate anomalies, particularly droughts or floods, in different parts of the globe

Linkages between the El Niño phenomenon and global climate anomalies were recognized by some scientists at the time of the 1982–83 event By early 1983 major drought periods were in progress in many regions around the globe, and other regions had experienced devastating floods The Indian summer monsoon of 1982 was late, erratic and withdrew early causing reduced summer crop yields; drought in the northern China plains led to decreased grain yield; a severe drought affected the dry season crop of Indonesia, Australia experienced one of the worst droughts of the century and out-of-control wildfires claimed 75 lives; drought in southern Africa threatened famine and disease, and drought in Northeast Brazil affected more than 14 million people. There was severe flooding on the Pacific Coast of South America and in Ecuador 600 lives were lost in landslides Six tropical cyclones affected French Polynesia leaving 250 000 homeless in Tahiti. The overall losses associated with the 1982–83 El Niño event were estimated to exceed 1 500 deaths and US $13 billion

The World Climate Programme (WCP) was established following the first World Climate Conference in 1979 The World Climate Research Programme (WCRP), jointly sponsored by the World Meteorological Organization (WMO) and the International Council for Science (ICSU), was established to coordinate and promote international climate research. A major initiative of the WCRP has been the Tropical Ocean Global Atmosphere (TOGA) project to describe, model and predict variability of the coupled ocean-atmosphere system on timescales of months to years The decade-long project, in planning from 1982, commenced in 1985 and efforts were directed at describing the tropical oceans and global atmosphere as a time-dependent system, identifying the mechanisms and processes underlying the variability, and initiating modelling and observing systems for prediction over the relevant timescales The 1997–98 El Niño event was the first to be observed by the full TOGA observing system, which had been completed by 1995.

One legacy of TOGA is the new monitoring systems that include satellite-borne instruments for remote sensing over data-sparse regions of the globe, moored ocean buoys and other instruments for direct observations of the climate system. For the first time ocean data are rapidly available High-speed computers now analyse the continuous data stream from around the globe and have provided enhanced awareness of the state of the climate system, including a capability for early warning. The TAO array of moored ocean buoys across the equatorial Pacific Ocean was crucial for providing timely information during the evolution of the 1997–98 event, particularly the changing subsurface temperatures of the ocean.

The 1982–83 event and studies of subsequent events have established that El Niño events are associated with negative values of the Southern Oscillation (higher than normal surface pressure over the Indo-Australian region and lower than normal surface pressure over the eastern South Pacific Ocean) The studies have also identified that positive values of the Southern Oscillation, when there is a stronger than normal summer monsoon over India and Asia, are associated with colder than normal sea surface temperatures over the eastern Pacific Ocean, called La Niña events.

The El Niño/Southern Oscillation, or ENSO, is now a well-developed model to link the fluctuations in sea surface temperature over the eastern equatorial Pacific Ocean with regional climate extremes in many parts of the globe. The recurring pattern of droughts and floods observed during 1877–78, 1888–89, 1972–73 and 1982–83 broadly describe the climate extremes associated with a warm ENSO (or El Niño) event. A cold ENSO event, or La Niña (i.e strong upwelling and colder than normal sea surface temperatures over the eastern Pacific Ocean) is associated with a strong Asian summer monsoon However, the impacts of the cold ENSO, while in general terms reflecting the reverse characteristics to the warm ENSO, are not strictly the opposite.

Recent studies of El Niño events that have occurred over the past century have also identified a characteristic pattern of development, evolution and decay linked to the seasonal cycle. The evolution of an El Niño event is generally first detected in the second quarter of the year (May–June) as an unusual warming of the surface waters of the eastern equatorial Pacific Ocean Within a few months an El Niño event is clearly observed as unusually warm water (a warm anomaly) that extends eastward from the central equatorial Pacific Ocean and spreads along the South American coast. The warm anomaly tends to decline later in the year and generally dissipates early in the following year

It is now clear that of the climate-related disasters that strike communities many, particularly those in tropical and subtropical regions, are associated with ENSO. This knowledge leads to a degree of predictability because once an event (either warm or cold) is observed to have commenced some typical impacts are likely to occur. However, no two events are identical and prediction skill of the onset of an event well in advance is still developing. Furthermore, ENSO is only one factor, albeit an important one, contributing to regional climate anomalies. The development of computer models of the coupled ocean-atmosphere system is heralding a powerful new tool for prediction of climate a season or more in advance. Experimental seasonal model-based forecasts of temperature and precipitation are being routinely produced by the European Centre for Medium-range Weather Prediction (ECMWF) and the International Research Institute for Climate Prediction (IRI)

The various national and international responses to climate disasters around the globe during the 1997–98 El Niño event point to a need for better application of existing climate knowledge and prediction capability, as well as further development of the reliability of these capabilities. National and regional plans within a framework of international cooperation are essential to prepare for and cope with climate risk. Clearly, knowledge is being applied to beneficial effect because the magnitude of deaths from famine and disease reported during the nineteenth century has significantly been reduced in the twentieth century But the level of loss and suffering from ENSO (warm and cold) events and their impacts are still unacceptably high and can be further reduced

The *Retrospective* draws on a series of presentations at the First Global Assessment of the 1997–98 El Niño Event, co-sponsored by the Government of Ecuador, the United Nations Task Force on El Niño and the Permanent Commission for the South Pacific, held in Guayaquil, Ecuador, 9–13 November 1998 (International Seminar on the 1997–98 El Niño Event: Evaluation and Projections), other national studies and from the scientific research community The *Retrospective* has been divided as follows.

Part I — The climate system

This section reviews the seasonal cycle of climate and describes El Niño/Southern Oscillation (ENSO) as an outcome of the coupled ocean-atmosphere system

Part II — The 1997–98 El Niño event

This section reviews the development and evolution of the 1997–98 El Niño event and the global pattern of climate extremes. This section also examines many of the regional climate anomalies and provides information on the extent of human impacts and losses on communities in the regions covered.

Part III — The way ahead

This section examines how science and technology, supporting climate information and prediction services, can be used in the service of community preparedness, early warning, and management of climate risk in society, particularly through the integration of science and technology with natural disaster reduction and sustainable development planning and policies.

Appendix

This section reviews relevant knowledge and processes of the climate system, including the Asian Monsoon and El Niño

The current levels of knowledge about ENSO and prediction skill provide a foundation to better cope with climate risk. Furthermore, integration of climate knowledge and prediction skills into multi-disciplinary preparedness and emergency response strategies will lead to saving of lives and development of communities that are more resilient to the impacts of climate extremes, whether or not linked to ENSO.

Since ENSO produces global-scale effects throughout a calendar year, it is necessary to explain events in both hemispheres in all seasons. The box opposite can be used as a guide when determining the months of a year applicable to the season on a given hemisphere.

Months	Northern Hemisphere	Southern Hemisphere
Dec Jan Feb	Winter	Summer
Mar Apr May	Spring	Autumn
Jun Jul Aug	Summer	Winter
Sep Oct Nov	Autumn	Spring