Part I

The Climate System

The seasonal cycle of climate

The annual north-south seasonal movement in the latitude band of maximum solar heating imposes an annual cycle on local climates and is the dominant cause of variability of the global climate system. However, the distribution of land and ocean between the hemispheres makes an important contribution to the seasonally changing characteristics of regional tropical climates. Land surfaces heat up and cool down more than the neighbouring oceans during the summer and winter. As a consequence, seasonal wind circulations, or monsoons, are established. The Asian monsoon, the impacts of monsoon winds on ocean surface temperatures, and the interaction between seasonal circulations in the tropics and the mid-latitudes are each important in the context of the year-to-year variability of climate.

In addition to external forcing by solar radiation and seasonally changing land surface characteristics, the climate system has variability in response to internal processes, particularly those relating to energy feedback within the oceans and atmosphere. The dynamics of these fluids and their boundary interactions are complex. As a consequence, in the atmosphere scales of motion vary from the seasonal planetary waves of the upper atmosphere to turbulent eddies related to wind gusts at the surface. The cyclones and anticyclones that make up the weather systems and the buoyant convection of local storms also have their place in the variability of the climate system. For their part, the oceans have scales of motion that range downward from ongoing inter-basin exchanges and basin-wide mid-latitude gyres.

The exchange of heat, moisture and momentum between the ocean and the atmosphere provides the linkage between the two fluid systems. Wind stress is an important factor in establishing the large-scale ocean circulations and it is the oceans that are the major contributor of latent energy (water vapour) and heat to the atmosphere. The overall motions of both systems transport heat from the tropics to the polar regions.

The El Niño/Southern Oscillation, or ENSO, is an outcome of the dynamic coupling between the oceans and the atmosphere. The El Niño has its focus in the surface waters of the Pacific Ocean and the life cycle of each event is different, but generally about a year in duration. The relatively long life cycle of the El Niño and the persistent anomalous forcing of the circulation of the atmosphere mean that, in many parts of the globe, El Niño is the most important contributor to atmospheric variability after the annual cycle of solar heating.

The following sections describe the El Niño phenomenon of the equatorial Pacific Ocean, the Southern Oscillation that is a major factor in the interannual variability of the cross-Pacific atmospheric circulation, and the coupled ocean-atmosphere El Niño/Southern Oscillation system (ENSO). The variability of the climate system associated with ENSO is influenced by and acts upon the broader range of climate processes. As background, the Appendix contains brief descriptions of some relevant climate processes and these add to the description of ENSO and its components that follows.

The El Niño

A pattern of abnormal warming of the surface coastal waters off Ecuador, Peru and Chile has become known as El Niño. Each event has typical characteristics, but each is unique in its actual time of onset, rate of development and intensity. The local warming is a manifestation of changes in the upper ocean layers and is linked to processes extending across the equatorial Pacific Ocean. El Niño affects more than the Pacific Coast of South America. This section will focus on the ocean surface layers of the equatorial Pacific Ocean and describe how prolonged abnormal warming observed in the near-shore waters of South America is but part of a more geographically extensive set of ocean processes.

There is a pronounced annual cycle of warming and cooling over the eastern equatorial Pacific Ocean. The temporal characteristics of the warming and cooling along the equator can be seen in longitude-time section (or Hovmöller diagram) of Figure I.1. The left panel represents the change with time (vertical axis) of actual sea surface temperature across the longitudes of the equatorial Pacific Ocean (horizontal axis). The annual appearance of warming off the coast of Ecuador (the right margin of the panel) occurs late in the year (about the time of Christmas, or the Christ Child — El Niño).

The maximum of sea surface temperature usually is reached in late summer of the Southern Hemisphere and is followed by strong cooling during the autumn and early winter months. During the Southern Hemisphere winter and early spring months (see Figure I.2b), the Trade Winds are relatively strong and induce upwelling and advection of deep water that is transported westward as a tongue of cold surface water along the equator into the central equatorial Pacific Ocean.

In some years the onset of cooling in the eastern Pacific Ocean appears to be late and relatively weak. Instead of coastal and equatorial upwelling there is a transport of warm water from the west. During these periods, as uniformly warm water spreads eastward across the equatorial Pacific Ocean, the usual (though seasonally varying) gradient of sea surface temperature across the equatorial Pacific Ocean is reduced and may even disappear. A characteristic of El Niño events is the abnormally warm sea surface temperatures that appear and persist for many months across the central and eastern equatorial Pacific Ocean.

The magnitude of the departure of sea surface temperatures from the normal seasonal cycle during warming and cooling events can be seen in the anomalies of temperature in the right panel of Figure I.1.

Figure I.1 Monthly mean sea surface temperatures (left panel) and anomalies (right panel) across the Pacific Ocean just along the equator (2°N to 2°S) for the period 1986 to 1998. There is a marked annual cycle of sea surface temperature over the eastern equatorial Pacific Ocean (left), particularly near the South American coast. When the annual cycle is removed (right) the periods of anomalous warming and cooling are identified. Warm and cold periods are identified as El Niño and La Niña events respectively if they are sufficiently intense and long lived to meet definitional criteria. (NOAA/PMEL (TAO Project), USA)

A Definition of El Niño

The term El Niño has evolved in its meaning over the years, leading to some confusion in its use and application. Because the El Niño phenomenon has achieved strong public recognition through its association with interannual climate variability around the world, there is a need to provide a more definitive meaning to its use. There have been a number of attempts to define El Niño, both qualitatively and quantitatively, but none has achieved universal recognition. A quantitative definition of El Niño proposed by the Climate Variability and Predictability (CLIVAR) project (Trenberth, 1997) is based on accepted concepts and designed to be consistent with previously recognized events. The criteria require that the five-month running mean of temperature anomaly in the region of the central equatorial Pacific Ocean, referred to as NIÑO 3.4 (5°N to 5°S and 170°W to 120°W), exceeds a threshold value of 0.4°C for a minimum of six months. This definition takes account of what was considered to be the key region for coupled ocean-atmosphere interactions. However, Trenberth acknowledged that the definition is not completely satisfactory and is still evolving with developing understanding of the characteristics of the phenomenon. The recommendation is that any use of the term should state which definition is being used.

In this *Retrospective*, 1997–98 is recognized as an El Niño event because of the strong warm anomaly of sea surface temperature across the central and eastern equatorial Pacific Ocean that first made its appearance in April/May of 1997 and became more extensive and persisted well into 1998. The region of sea surface temperature anomaly associated with the event reached maximum extent and strongest intensity in late 1997 before collapsing dramatically, especially in the region of the central equatorial Pacific Ocean during mid-1998. Reference to onset, maturity and cessation generally apply to characteristics of the event.

The extent of the abnormally warm sea surface temperature and the maximum intensity of the anomaly are what characterize the 1997–98 El Niño event as possibly the strongest warming event of the Pacific Ocean of the twentieth century, and at least of comparable magnitude to the 1982–83 event.

Until a universally agreed definition of an El Niño event emerges there will continue to be debate as to the status of a number of the weaker warming episodes that have been observed, including some of those for the period 1986–96. There will also be debate as to whether the period 1991–95 comprised a sequence of discrete events, or was one long event.

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