surface westerly wind forcing. However, episodic wind forcing is not a sufficient condition for El Niño events to occur, since such forcing is evident during non-El Niño years as well.

During an El Niño event the cross-Pacific sea level setup relaxes as the Trade Winds weaken and warm water moves eastward. The change in equatorial cross-Pacific setup can be seen from the records of sea level, both in the western Pacific Ocean and the eastern Pacific Ocean. Figure I.3 shows the anomaly of sea level, corrected for atmospheric pressure, at Santa Cruz, Ecuador (lat 0.45°S, long 90.19°W) and Pohnpei, Federated States of Micronesia (lat 6.59°N, long 158.15°W) during the 1991–92 El Niño event. In the west (Pohnpei) the sea level initially fell about 20 cm and then recovered while in the east (Santa Cruz) the sea level initially rose about 20 cm and then returned to normal. These patterns are consistent with eastward flowing water across the Pacific Ocean as the El Niño event develops.

The spatial extent of warmer than normal sea surface temperature over the central and eastern Pacific Ocean during the mature phase of an El Niño event can be gauged from the anomaly pattern for January 1992 (Figure I.4). For this particular event the focus of warming is along an equatorial band in the central Pacific Ocean, but there are also warm anomalies in the eastern Pacific Ocean and extending along the coastal margins of tropical South and Central America.

The pattern of warm sea surface temperature anomalies of Figure I.4 outlines the area of warm water that accumulates in the surface layers of the central and eastern equatorial Pacific Ocean and illustrates the extensive rearrangement of energy storage that occurs during an El Niño event. The relatively warm water across the central and eastern equatorial Pacific Ocean becomes available to act as a source of energy to the atmosphere. The unusual warming of the eastern Pacific lasts for up to a year and represents a long period of anomalous forcing of the atmospheric circulation by the El Niño event.

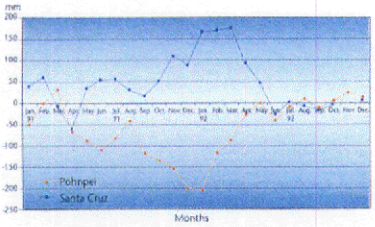

Figure I.3
Monthly sea level anomaly for Santa Cruz, Ecuador (blue line) and Pohnpei (red line), Federated States of Micronesia showing rise in sea level (mm) in the east and fall of sea level in the west during the El Niño event of 1991–92.
(University of Hawaii Sea Level Center)

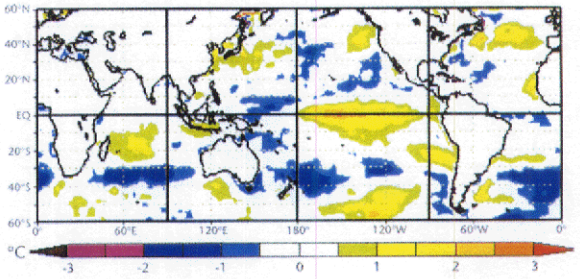

Figure I.4
Pattern of sea surface temperature anomaly for near the mature phase of an El Niño event (January 1992). The abnormal warming of this event is mainly in the equatorial central Pacific Ocean and the warming over the eastern equatorial Pacific Ocean is relatively weak.
(NOAA/NCEP, USA)

The Southern Oscillation

During the early decades of the twentieth century, Sir Gilbert Walker, then Director-General of British Observatories in India, identified the tropical cross-Pacific atmospheric circulation that now is generally referred to by his name. The Walker Circulation is a simple picture of the zonal cross-Pacific airflow that takes account of neither seasonal variability nor year-to-year differences. However, the description captures the essential zonal atmospheric overturning processes across the Pacific Ocean:

- Surface atmospheric pressure is higher over the east than the west;
- Surface Trade Winds blow from east to west and accumulate heat and moisture from the underlying tropical oceans;
- Deep tropical atmospheric convection clouds, with rising air and heavy rainfall, are experienced in the converging Trade Winds and monsoon over the western tropical Pacific Ocean and Asia respectively;
- Westerly winds provide a return flow in the high atmosphere; and
- Clear skies, subsiding air and relative aridity are experienced over the eastern Pacific Ocean.

Significant year-to-year variability in the tropical cross-Pacific surface atmospheric pressure gradient and the Trade Winds are features of the Walker Circulation that have been known for nearly a century. Lack of data prevented detailed elaboration of the variability but an early linkage was made between the cross-Pacific surface atmospheric pressure gradient and the strength of the Asian summer monsoon. The year-to-year variability of the Walker