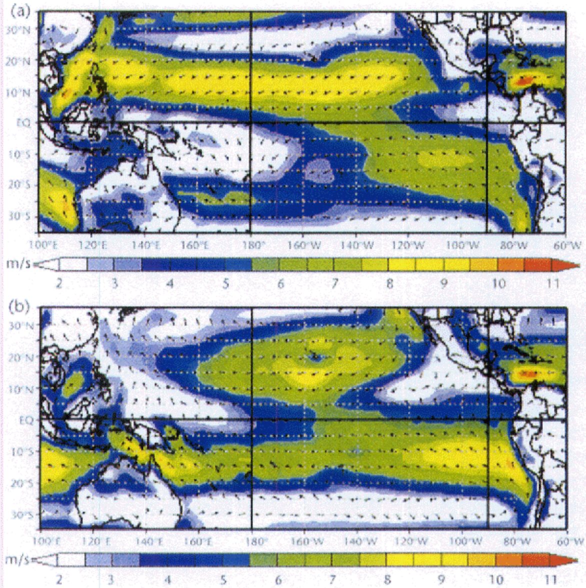

Figure I.2
Average surface vector winds over the Pacific Ocean during a) Northern Hemisphere winter (December, January and February); and b) Southern Hemisphere winter (June, July and August). The Peruvian current and coastal upwelling off South America are strongest during the Southern Hemisphere winter when the Trade Winds over the region are strongest. During the Northern Hemisphere winter, when the intertropical convergence zone moves southward, there is an easing of the Trade Winds and reversal of the current offshore from Ecuador and northern Peru.
(NOAA/CDC, USA from NCEP/NCAR reanalysis, USA)

events. The anomalous warming and cooling are part of the natural variability of the surface layers of the equatorial Pacific Ocean. The amount, the duration and the geographical focus of warming and cooling are important in forcing anomalous circulations in the atmosphere.

The annual cycle of upper layer cooling of the central and eastern equatorial Pacific Ocean waters is strongly influenced by the seasonal waxing and waning of surface winds. The Trade Winds north of the equator are strongest during the Northern Hemisphere winter (see Figure I.2a) and strongest south of the equator during the Southern Hemisphere winter (see Figure I.2b). The easing of the southeast winds over the eastern equatorial Pacific Ocean during the Northern Hemisphere winter is very evident in Figure I.2a. Therefore, it is not unexpected that the Peruvian current bringing cold water towards the equator and the offshore upwelling both have an annual cycle and are at a peak during the Southern Hemisphere winter.

Despite the influence of seasonal winds on the annual cycle of warming and cooling, the periods of anomalous warming of the surface layers of the central and eastern Pacific Ocean appear to have their origins in the ocean dynamics operating across the equatorial Pacific Ocean.

A prevailing theory of ENSO is that the ocean and atmosphere coupling across the equatorial Pacific Ocean behaves as a delayed oscillator and its evolution on interannual timescales is governed by the interplay between large-scale equatorial ocean wave processes and ocean-atmosphere feedbacks. An important precursor to an El Niño event is the build-up of heat content in the surface layers of the western Pacific Ocean. Persisting Trade Winds are important for generating downwelling Rossby waves that travel westwards and produce a deepening of the thermocline in the western Pacific Ocean. An expansion in the overall volume of warm surface water in the western Pacific Ocean is associated with the deepening thermocline. At the western side of the Pacific Ocean, reflection off the equator of ocean Rossby waves can generate a Kelvin wave that propagates eastwards along the equator and generates downwelling and deepening of the thermocline in the east.

More recently attention has been directed toward the role of tropical surface winds and their intraseasonal variations in the development of El Niño events. Known as Madden-Julian Oscillations, waves in the atmosphere with a 30- to 60-day period originate over the Indian Ocean and propagate eastwards. Deep atmospheric convection and low-level westerly winds that occur with the Madden-Julian Oscillation are usually only associated with relatively warm ocean surface waters (warmer than approximately 28°C to 29°C). The Madden-Julian Oscillation goes through a normal seasonal cycle with largest amplitude in the summer and autumn of the Southern Hemisphere (December through May).

The potential role of the Madden-Julian Oscillation in the development of an El Niño event can be identified through westerly wind bursts lasting several days to weeks that are associated with these waves. A westerly wind burst over the western Pacific Ocean causes lateral drift of local eastward directed wind-driven currents towards the equator. The resulting convergence at the ocean surface induces downwelling and downward pressure on the thermocline. The overall effect of a westerly wind burst of the Madden-Julian Oscillation is to generate a Kelvin wave that propagates eastward and both deepens the thermocline and transports warm surface water. A Kelvin wave has a travel time of approximately two months for its crossing of the equatorial Pacific Ocean.

All El Niño events since the 1950s have been associated with elevated levels of