4. COASTAL OCEANOGRAPHIC INFLUENCES

4.1 Geological Structure of Central America and the Adjacent Ocean Basins

The mountains in Central America developed when the crustal plates surrounding the Caribbean Plate (which contains the Caribbean Sea and most of the islands surrounding it) either slid over it, or dived beneath the Caribbean Plate; see Figs. 4.1 and 4.2. The mountains are either old rocks forced upward, or later volcanic intrusions. More than 250 volcanoes stand in a row bordering the Pacific edge of Central America; see Fig. 4.3. This mountain-building history results in a wide variety of landforms and landscapes in Central America. One result from this history is the Middle America Trench that lies offshore, adjacent to the Pacific coastline northwestward from Costa Rica. A similar trench occurs in the northwestern Caribbean Sea, offshore from the Cayman Islands. These trenches have resulted from the collision between crustal plates in the earth's surface, when one plate was forced beneath another plate in the trench regions. Figure 4.4 illustrates the location of the Middle America Trench; it also shows the Cayman Rift to the west of Jamaica in the Caribbean Sea.

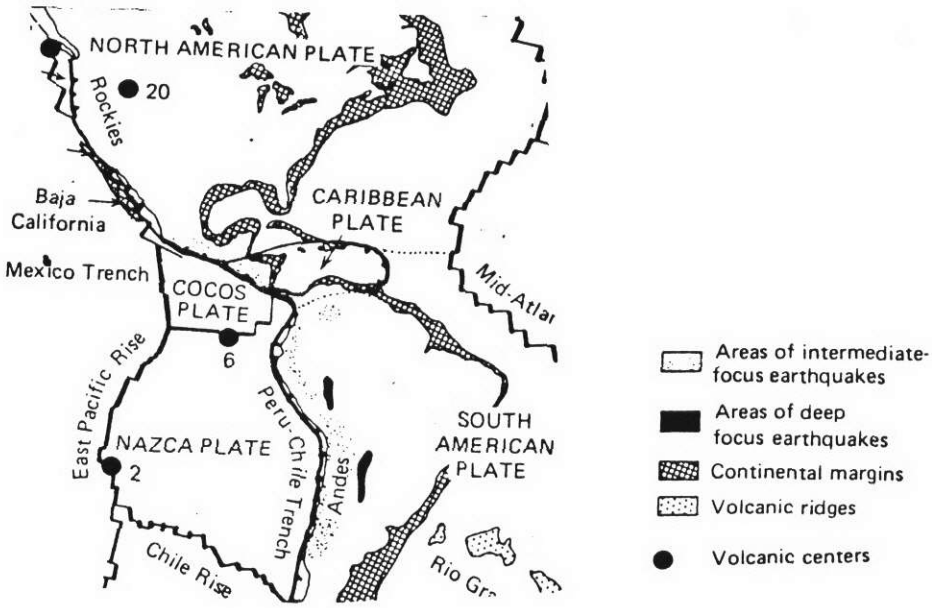

Figure 4.1: The Crustal Plates that affect the Central American region: North American; Caribbean; Cocos; Nazca and South American. (Adapted from Gross (1982).)

Figure 4.2: Motion of Crustal Plates, and regions of intensive earthquake activity as indicated by dots. Each plate moves the distance equivalent to the length of the arrow in 20 million years. (Adapted from Leet, Judson and Kauffman (1978).)

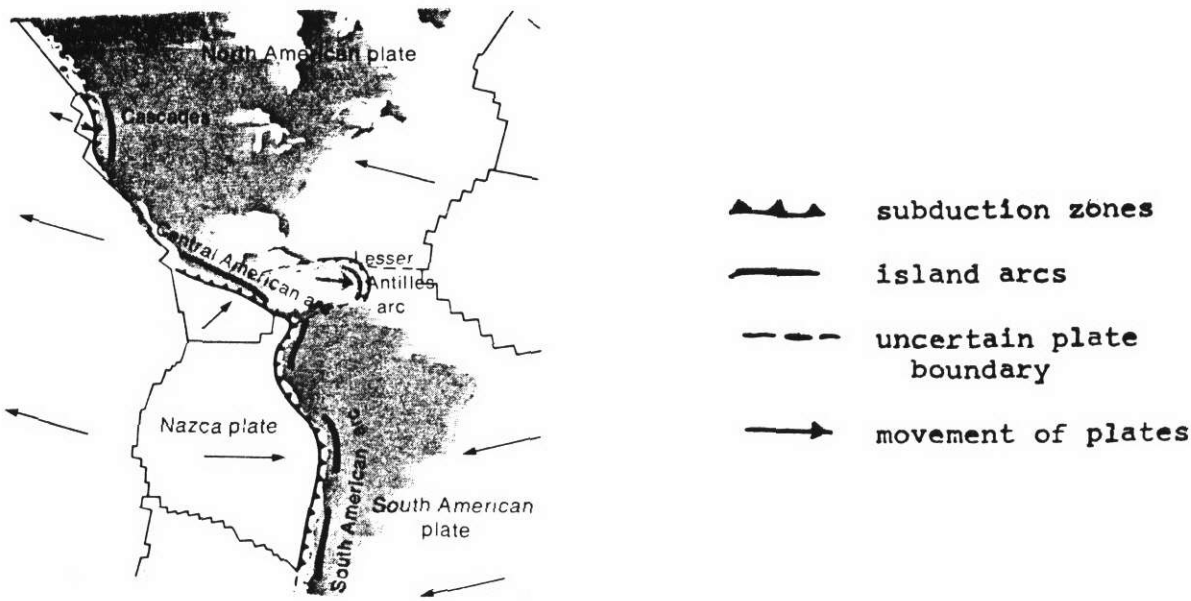

Figure 4.3: Volcanic Fronts and Island Arcs develop parallel to the trenches or deeps marked by subduction zones, where plates are consumed into the inner earth; plates form originally at the mid-ocean ridges. (Adapted from Skinner (1980).)

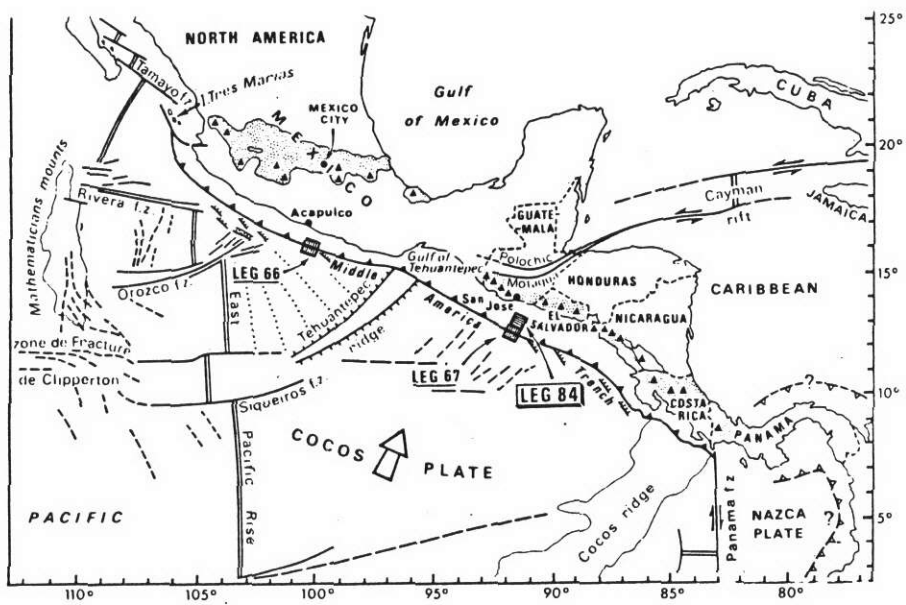

Figure 4.4: Location of the Middle America Trench is shown adjacent to the Pacific coastline northwestward from Costa Rica, where the Cocos Plate is forced underneath the Caribbean and North American Plates in the earth's crust; the location of the Cayman Rift is also shown in the northwestern Caribbean Sea, along the boundary of the Caribbean Plate. (Adapted from Aubouin et al. (1982).)

Seismicity. The Pacific coast of Central America is very active seismically, while only scattered epicenters appear on the shelf off the Caribbean coast. Thus, while the Caribbean coast and the land area of Central America should be considered relatively stable, the shelf has shown continual signs of seismic activity, as indicated by Collins et al. (1970). Figure 4.5 illustrates the epicenter density of the region; note that recorded loci are usually shallow.

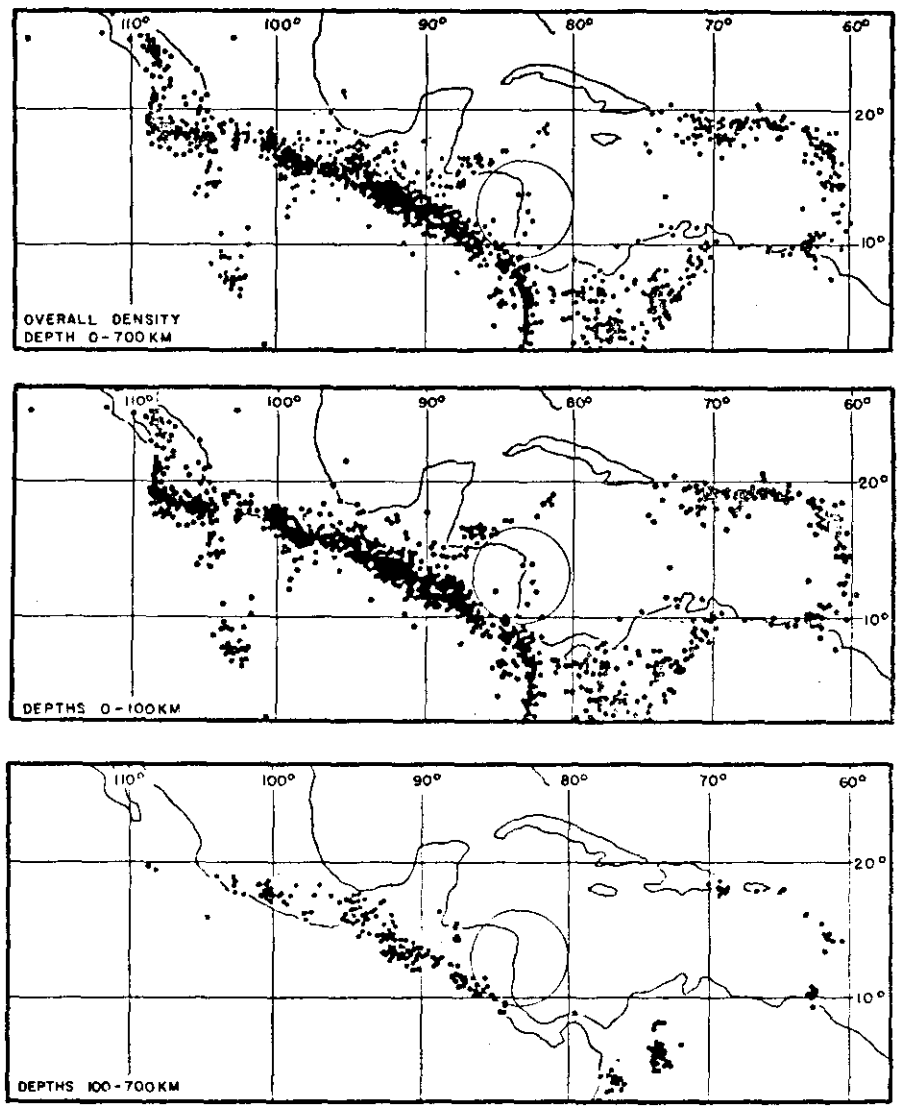

Figure 4.5: Epicenter Density in Regions Adjacent to Central America, (1961-1967). Ignore the large circle (from original work) near Nicaragua (Collins et al., 1970).

Ocean Currents. Long-term mean ocean current charts adjacent to the coastlines of North, Central and South America have been produced by Meehl (1982). He made use of a seasonal ocean current data set from long-term mean currents derived from ship-drift shown on pilot charts; these data have been digitized on a 5° grid (see Fig. 4.6). These data agree favorably with ocean currents measured by buoys and current meters. Variability of surface current direction is summarized in Fig. 4.7, which indicates no seasonal current direction reversal occurs in the Caribbean Sea, but pronounced seasonal change (April to October) occurs in the eastern tropical North and South Pacific Oceans. This is described in detail in the Pacific Ocean discussion.

In the western Caribbean Sea, the ocean current flows in a relatively constant direction, toward the northwest, throughout the year. In October, a counterflow appears along the coast of Nicaragua, Costa Rica and Panama directed toward the southeast, as part of an eddy which forms to the west of the main ocean current flow.

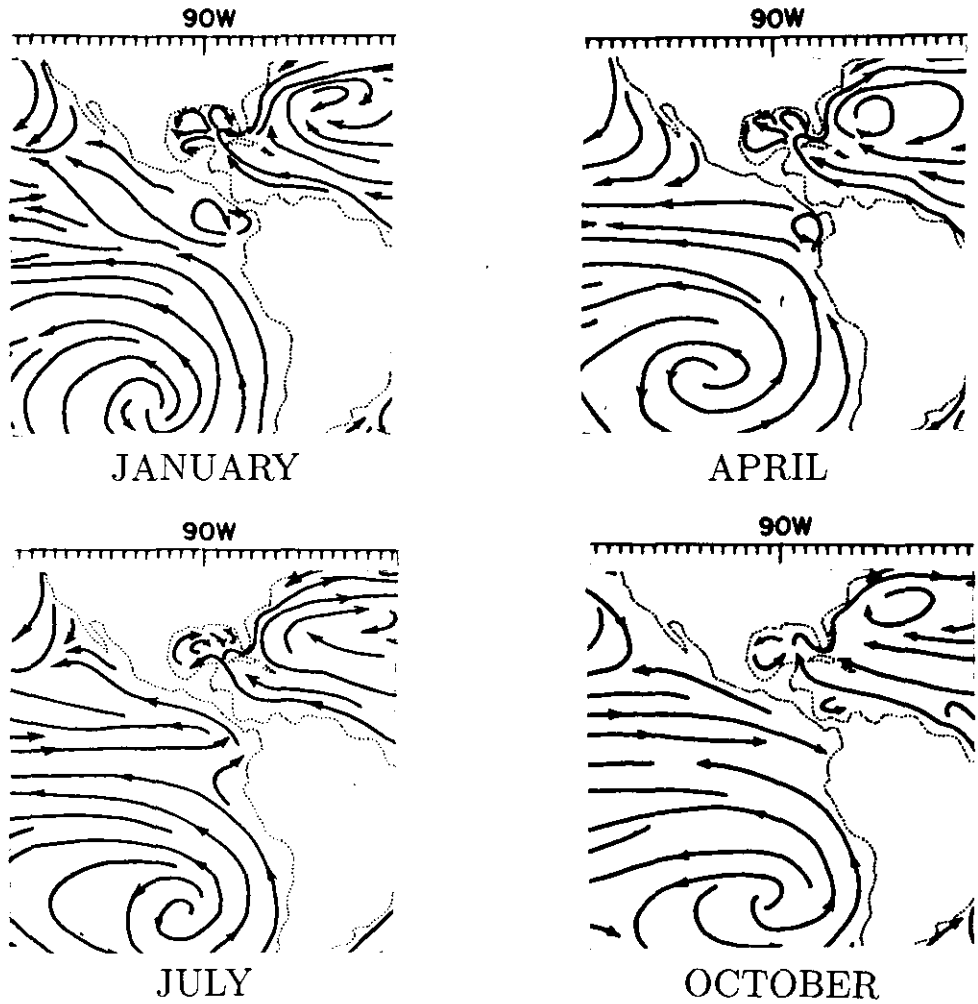

Figure 4.6: Observed Ocean Surface Currents; seasonal long-term currents based on ship-drift data from pilot charts (adapted from Meehl, 1982).

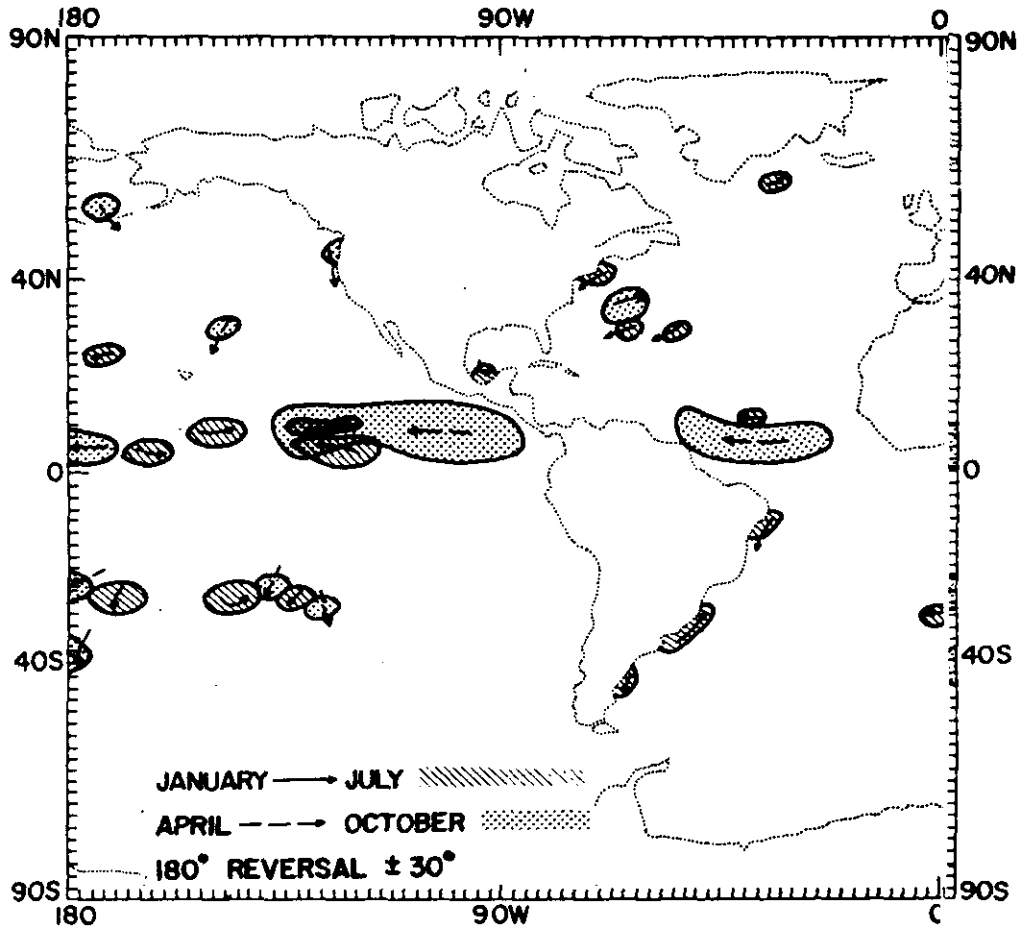

Figure 4.7: Surface Current Variability. Reversal change in direction (180° ± 30°) between two seasons: January reversing in July–solid arrows; April reversing in October–dashed arrows. (Adapted from Meehl, 1982.)

Tides along the Central American Coast. Figure 4.8 from Gross (1982) shows that the tides along the coasts of Central American are mixed tides, and the tidal range for spring tides is shown at three stations. The tidal range is about 10 times greater along the Pacific coastline than it is along the Caribbean coast. Collins et al. (1970) note the tides along the Nicaraguan coast are mixed tides in the Caribbean (semi-diurnal plus diurnal, that yield two unequal tidal cycles per day); and that the tides progress there from south to north, usually with a range of less than two feet. Three stations (locations are shown in Fig. 4.25) are listed in Table 4.1, with high tide at Puerto Cabezas arriving 49 minutes after high tide at the Bluefields Lagoon entrance; and high tide occurs at Cabo Gracias a Dios with a delay of 3 hours, 31 minutes after it arrives at Bluefields. This Table summarizes tidal range and levels for these stations. Murray et al. (1982) note the tidal range on Miskito Bank off Nicaragua is about 20 cm.

Table 4.1: Summary of Tides at Coastal Stations along Caribbean Coast of Nicaragua (Collins et al., 1970)

Station	Mean Tide Range	Diurnal Tide Range	Spring Tide Range	Mean Tide Level
Cabo Gracias a Dios	1.2 feet	1.6 feet	1.9 feet	0.8 feet
Puerto Cabezas	1.4 feet	1.9 feet	2.1 feet	0.7 feet
Bluefields (Lagoon Entrance)	0.7 feet	1.0 feet	1.0 feet	0.3 feet

Tidal currents occur with greatest speeds at high and low tides, except near Cabo Gracias a Dios, where the strongest currents occur at mid-tide. The currents are small, usually less that 0.25 kt, according to Collins et al. (1970). On Miskito Bank, the maximum current speed is 7 cm/sec from calculations by Murray et al. (1982). They note maximum observed tidal currents at four shelf locations were 4–8 cm/sec; these tidal currents appear to be a major component of the total currents in the central Miskito Bank region; however, these tidal current values are nearly an order of magnitude smaller than the higher current speeds of the Coastal Boundary Layer nearshore (see later discussion).

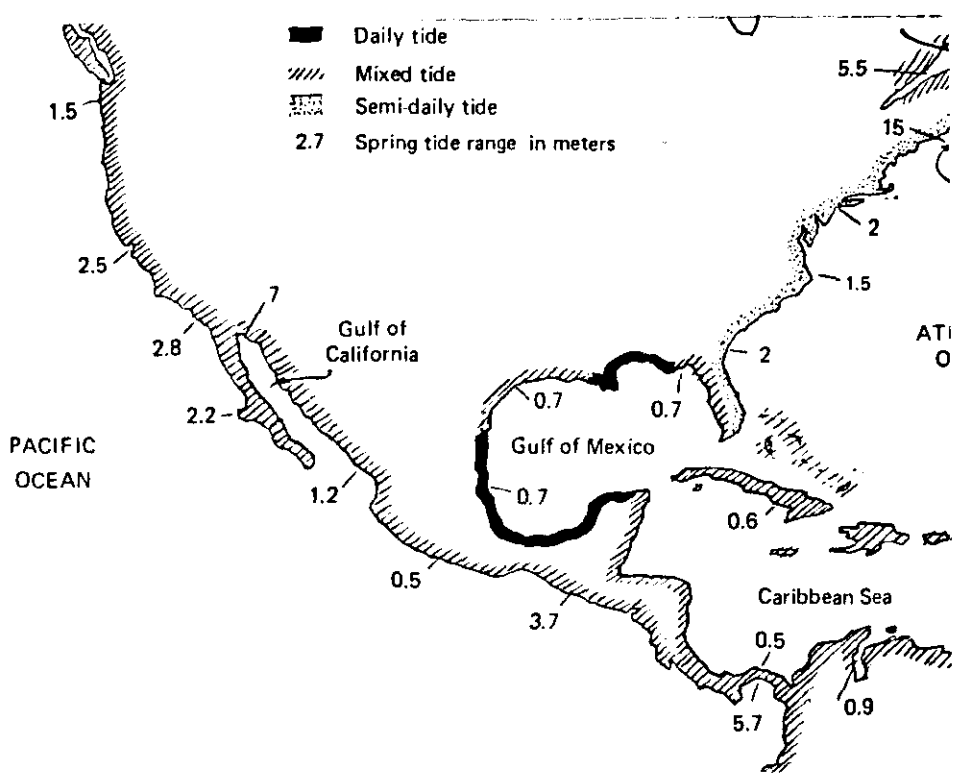

Figure 4.8: Types of Tides and Spring Tide Ranges (in meters) along indicated coastlines (adapted from Gross, 1982)

Sea-Surface Temperatures Adjacent to Central America. Since Central America is in tropical latitudes, between 8°N and 19°N, temperatures of the sea surface adjacent to this landmass are relatively warm. However, there are influences which act to provide small seasonal fluctuations in these temperatures. Some of these seasonal effects are in response to influences well outside the immediate coastal region of Central America .

On the other hand, the local wind field also affects these temperatures as the winds respond to seasonal influences that change their direction and speed. These seasonal effects from winds produce localized upwelling, with associated cooler temperatures, seaward from the Pacific coastline. This occurs when strong Northeast Tradewinds are able to penetrate through mountain passes or low-lying regions in Central America, and reach beyond the Pacific coastline during northern hemisphere winter and spring. During these seasons, also, less intense upwelling is observed in the southern Caribbean, along the northwestern coast of Venezuela.

Advection of cooler water in response to wind occurs in the Gulf of Panama in winter and spring, as well as along the equator, as water is carried northward and westward from the upwelling region off South America.

Local heating and cooling of the water surface also is affected by seasonal changes in cloud cover which occurs as the ITCZ[79] moves and changes in its progression through this region.

Charts showing wind flow direction and wind speed, and the associated sea-surface temperature charts have been adapted from Sadler et al. (1987) for the months of January, April, July and October. These are shown as Figs. 4.9 through 4.12. The following brief summary depends on these Figures.

Western Caribbean Sea Coastline of Central America: in January, temperatures are 26°C or slightly higher; by April, these have increased to 27°C or slightly higher; in July, temperatures are near 28°C; in October, a maximum temperature center has developed near Belize with temperatures of 28 to 29°C. Temperature gradients are weak throughout the year as coastal temperatures undergo their small annual variation.

Eastern North Pacific Ocean Coastline along Central America: this region lies between the upwelling centers observed at higher latitudes along the North American and South American western coasts; and only a small area in the Gulf of Panama is affected by advection from the South American upwelling during January–April, with temperatures of 26 to 27°C there. Local upwelling along the Pacific coastline in January produces two small upwelling centers with cool temperatures (less than 26°C) off the Guatemala–Mexican border, and off Nicaragua; these alternate with warm centers along the coastline; temperatures are 27°C plus off Honduras–Guatemala and 28°C plus off Costa Rica. In April, an upwelling center off Nicaragua drives temperatures below 28°C; this separates two warmer centers–one off Guatemala and one off Costa Rica, each with temperatures above 29°C. Temperature gradients along the coastline are much more pronounced than along the Caribbean coastline. This changes by July, when there is a very weak temperature

[79]To provide continuity with the meteorological sections, the acronym ITCZ (for Inter-tropical Convergence Zone) will be used vice ITC.

gradient along the Pacific coastline in the absence of pronounced upwelling. Temperatures range from a few tenths degree C above and below 28°C. In October, the temperature maximum (above 29°C) off Guatemala contributes to the moderate temperature gradient along the Guatemala–El Salvador coastline; the gradient becomes very weak from Nicaragua southeastward, with temperatures there just below 28°C.

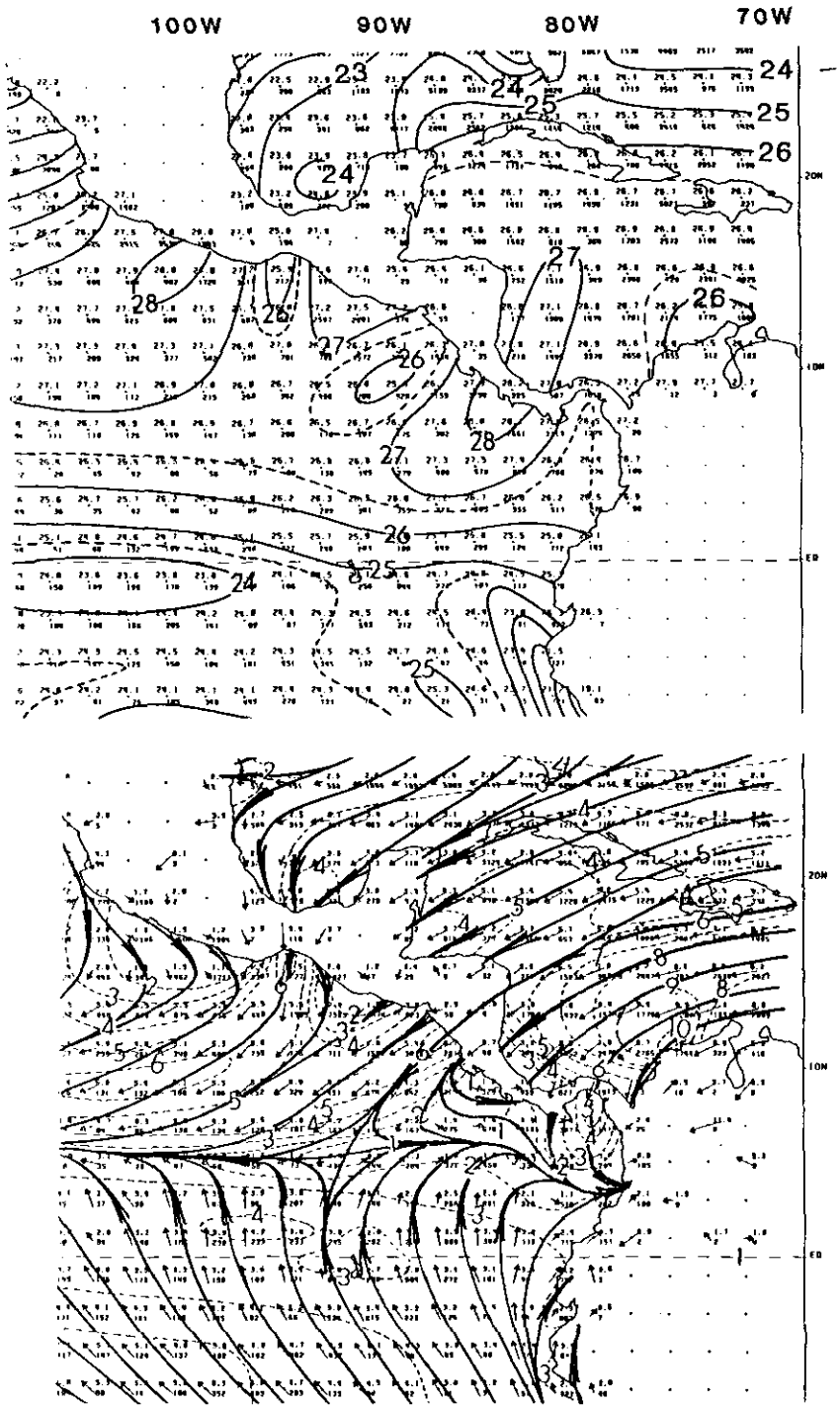

Figure 4.9: Sea-Surface Temperature (SST) and Wind Pattern for January. SST in °C; streamlines (solid lines), wind speed (in m sec^{-1} (dashed lines)) (adapted from Sadler et al., 1987)

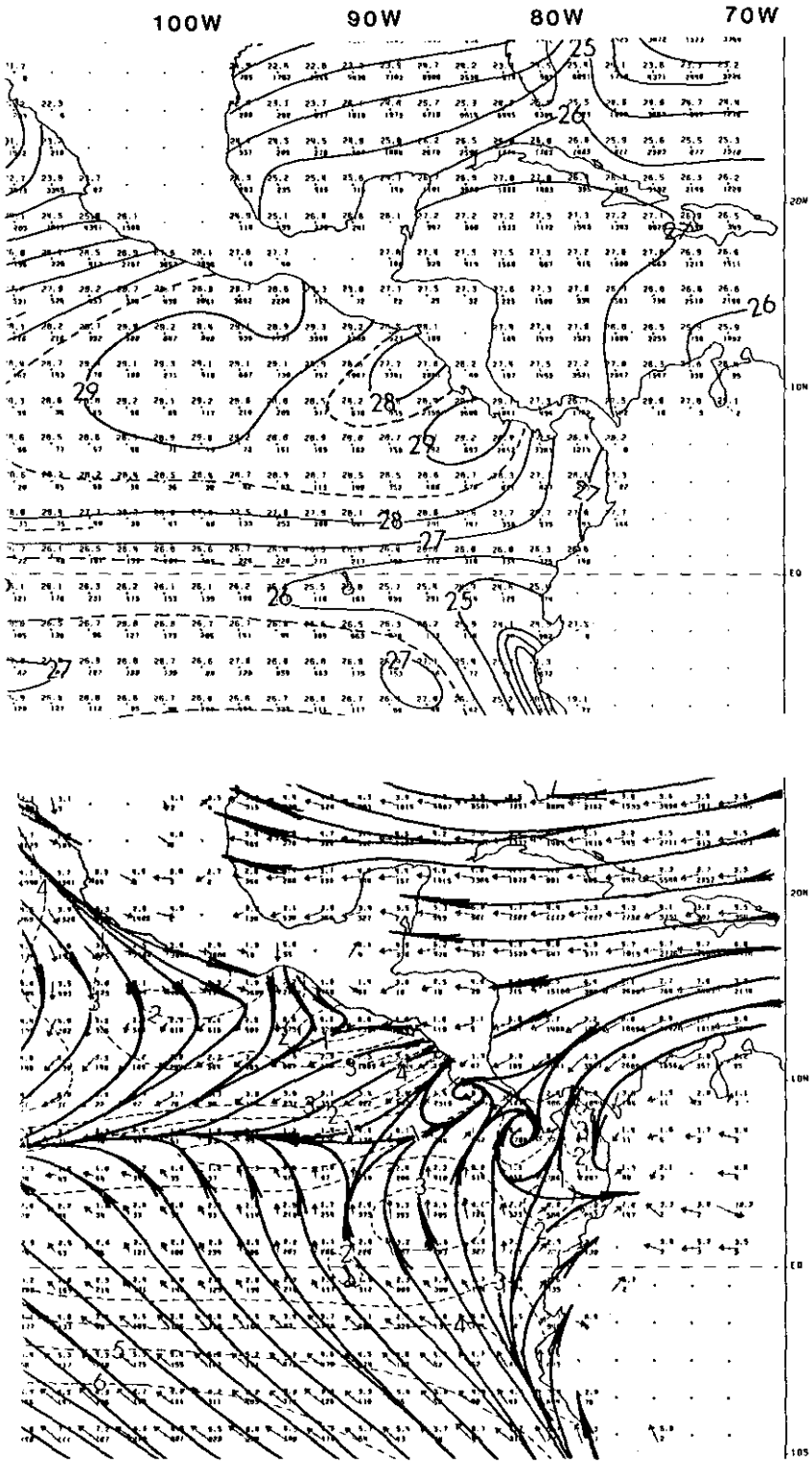

Figure 4.10: As in Fig. 4.9 for April (adapted from Sadler et al., 1987)

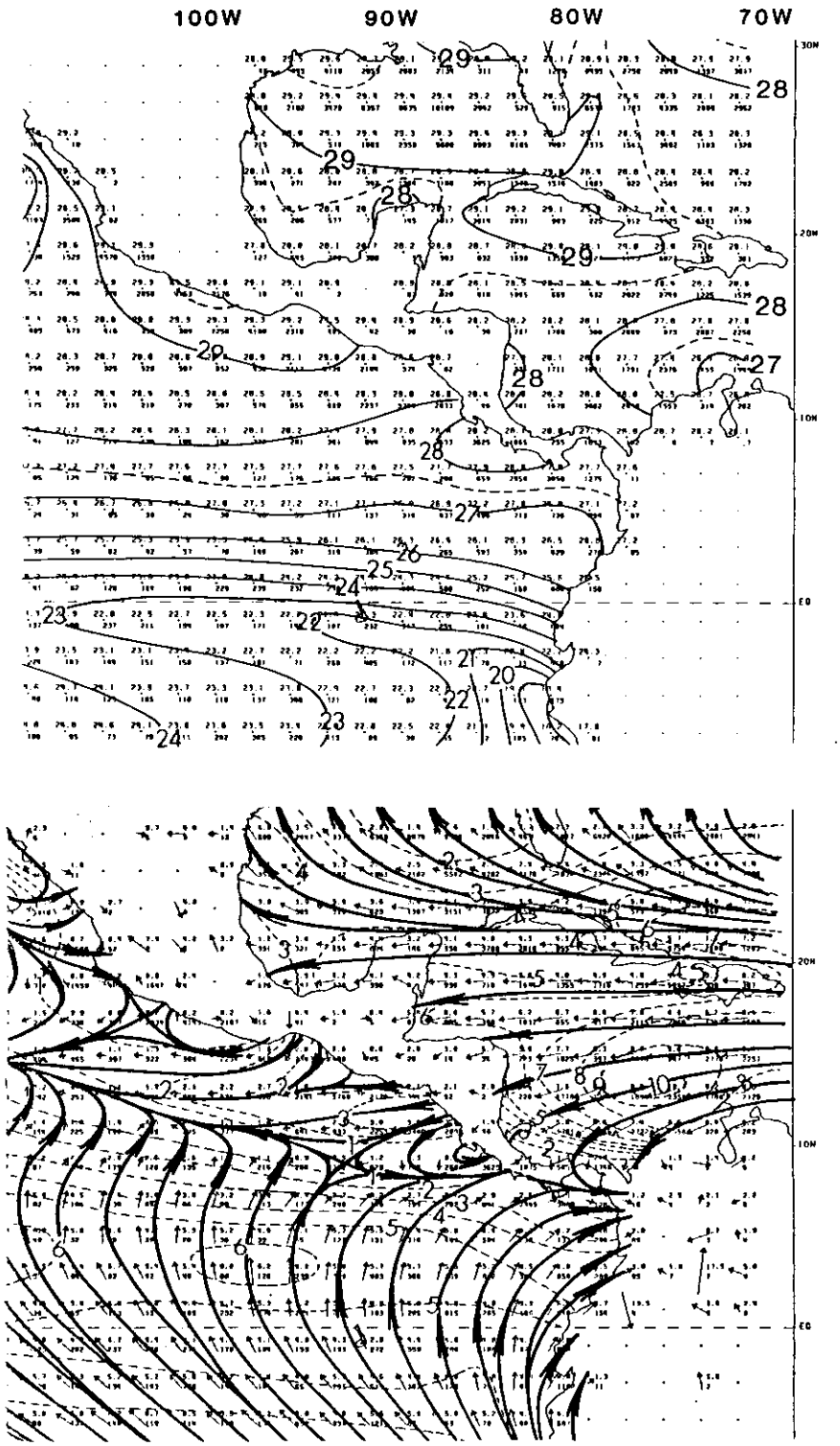

Figure 4.11: As in Fig. 4.9 for July (adapted from Sadler et al., 1987)

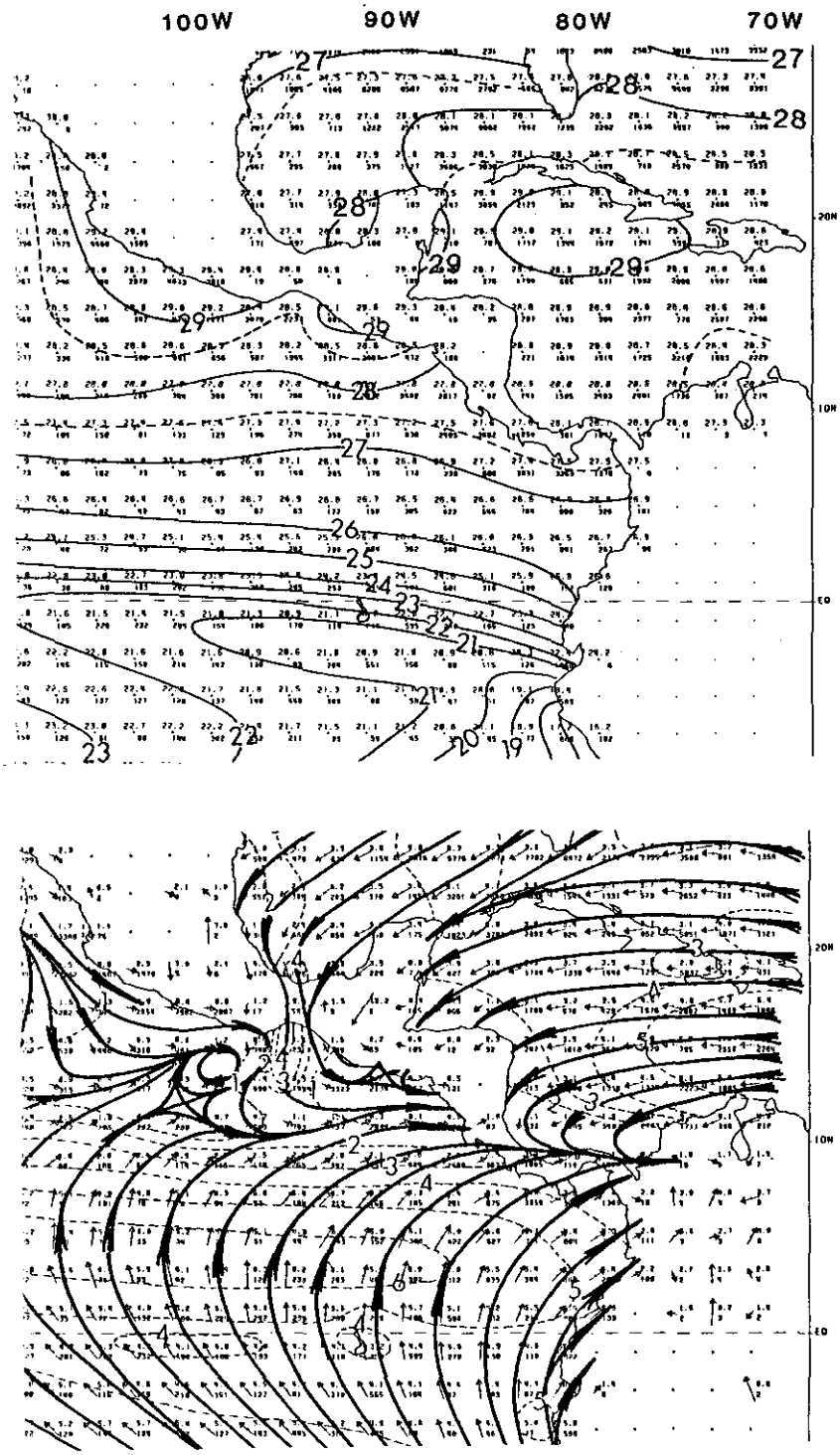

Figure 4.12: As in Fig. 4.9 for October (adapted from Sadler et al., 1987)