Tropical Cyclones

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Climatology and Impacts in the South Pacific

James P. Terry

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For Daisy, Dylan and Joshua

Preface and Acknowledgements

The South Pacific is an almost incomprehensibly vast ocean. Within it lie thousands of islands belonging to over 15 developing nations and territories. These islands display enormous physical diversity. They may be large or small, rugged volcanic mountains with high elevations, flat limestone platforms or tiny coral islets resting just above sea level on top of coral reefs. Many islands are remote and uninhabited while others are densely populated with bustling towns and expanding cities. In terms of climate, the South Pacific is one of the major ocean basins where tropical cyclones occur. Most tropical islands are affected periodically by the passage of these violent storms, which cause loss of life, disrupt society and (my main interest) often produce spectacular changes in island physical environments. It is perhaps surprising then that no book has previously been dedicated to describing either the climatology of tropical cyclones in the South Pacific or their physical impacts on the islands they encounter.

The aim of this book therefore is to link two central themes – tropical cyclones and the physical environments of islands in the South Pacific. The first half of the book describes the characteristics and behaviour of tropical cyclones in the region, and assesses the outlook for the future in the context of climate change. The second half then illustrates the importance of these storms for island environments, concentrating on geomorphological and hydrological responses. Regional examples and case studies are used to show how coral reefs, coastlines, hillslopes and rivers are all affected, and how sometimes tropical cyclones can even cause the destruction of existing islands or the formation of entirely new ones.

It is certainly the case that plenty has already been written about tropical cyclones and a great many research papers may be found in scientific journals. But the language of these is not easily accessible to all. And so it shouldn't be, because the content is intended for specialist audiences – climatologists, meteorologists, physicists, 'tempestologists' and those from associated disciplines. My own experience, from over two decades of teaching physical geography at university, is that to try to cajole students without the necessary science backgrounds to read and use such materials is often a difficult task. Although most students are keen to learn, they tend to be too shy of revealing an inability, either real or perceived, to grasp fully the tricky mathematical and physical concepts underpinning the thermodynamic behaviour of our atmosphere and the processes leading to the formation of tropical cyclones. I sympathise with their plight.

With this in mind, I have written this book to be illustrative yet concise, and informative but non-technical. I hope that this makes it attractive to a diverse readership, especially to those interested in climate and climatic extremes, tropical islands, tropical environments, physical geography, geomorphology and the South Pacific region in general.

I am very much indebted to many people for their help in researching, writing, illustrating and producing this book. Foremost, I wish to thank Professor Cliff Ollier for allowing me to benefit from his enormous wisdom on writing a readable manuscript, and Professor Patrick Nunn for offering much sensible advice while reviewing the penultimate draft. Marie Puddister and Daisy Terry accomplished a great deal of hard work preparing early versions of many of the diagrams, for which I am grateful. A large number of other individuals provided much-needed assistance in the field, gave me unlimited access to their original unpublished data and photographs, shared their personal experiences or simply joined in useful and stimulating discussion. A few of those I would especially like to mention are Michael Bonte, Austin Bowden-Kirby, Ami Chand, Pradeep Chand, Douglas Clark, Antoine DeBiran, Finiasi Faga, Sitaram Garimella, Robert Gouyet, Tetsushi Hidaka, Kei Kawai, Ray Kostaschuk, Ravind Kumar, Riteshni Lata, Simon McGree, Rajendra Prasad, Rishi Raj, Nick Rollings, Roshni Singh, Randy Thaman, George Vakatawa, Aliti Vunisea and Geoffroy Wotling. To the many other people, too numerous to name individually, who helped in some way, I extend my sincere appreciation.

For giving me the inspiration and motivation to write this book, I am grateful to all my students in physical geography, both past and present, at The University of the South Pacific. The work presented herein would also not have been possible without the generous financial support of the University Research Committee.

During the last decade of fieldwork in my adopted home in the South Pacific, I have been fortunate enough to visit many islands and stay in traditional villages with the local people. On remote and isolated islands especially, daily life can be a struggle for the people who live there. Tropical cyclones certainly don't help. One has to admire the way Pacific islanders endure the physical challenges that such climatic hazards present. I offer my heartfelt thanks for the willing help, guidance, hospitality and companionship offered by all the Pacific islanders I have been privileged to meet.

J. P. Terry
Suva, January 2007

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Part I
Tropical Cyclones in the South Pacific

Chapter 1
Setting the Scene

1.1 Introduction

The islands of the tropical South Pacific are vulnerable to a variety of natural hazards. Some are associated with the vagaries of climate, such as tropical cyclones (elsewhere called hurricanes or typhoons), droughts and floods, whereas others are geological in origin, such as volcanic eruptions, earthquakes and tsunamis. The main difference between these two groups of hazards concerns the timescale on which they happen. If we decide arbitrarily to deal on the timescale of a human lifespan, then the effects of a major geological event will be experienced perhaps only once or twice in a lifetime, or possibly not at all. In contrast, tropical cyclones and associated hazards are felt more frequently, perhaps every few years.

The aim of this book is to explore the characteristics and behaviour of tropical cyclones in the South Pacific and examine the remarkable impacts that these violent storms have on the physical environments of the islands they encounter. For the island nations of the South Pacific, tropical cyclones are nature's most intense phenomena, and their attendant conditions of tremendous seas, fierce winds, storm surge and torrential precipitation can inflict much damage on both human and natural landscapes. The combination of their severe nature and regular incidence means that tropical cyclones and their impacts are a major concern across the South Pacific; in short they are storms to be reckoned with for the people who live in this region.

It is something of a tradition in the opening sections of texts on tropical cyclones to quote a passage from the writings or diary of an early European explorer or missionary in the tropics who describes a historically severe event. Such excerpts are a vivid way to present an account of a tropical cyclone in more dramatic prose than the rather matter-of-fact language of science. The following example, recounted in Kerr (1976, p. 1), is a colourful account by the Reverend J. Williams (1837, p. 331–334), of a storm he experienced at Rarotonga in the Cook Islands:

The next day was the Sabbath, and it was one of gloom and distress. The wind blew most furiously, and the rain descended in torrents. . . . Towards evening the storm increased; trees were rent, and houses began to fall. . . . (Monday morning). . . . the whole island trembled to its very centre as the infuriated billows burst upon its shore.

Narratives of storms that are personal favourites of mine are the pair of excerpts highlighted by Visher (1925, p. 134), recollecting the tropical cyclone that struck Samoa on 16 March 1889. The tale of this storm is particularly astonishing as it is credited with having prevented war between the United States and Germany at the time! According to the Editor of the Independent newspaper of New York (1915), six warships of these nations were occupying the harbour of Apia, the Samoan capital, and were on the point of opening fire on each other when the storm hit (excerpt [1] below). The outcome of the cyclone's effect on the hostilities was assigned great significance on the turn of world history by the writer Robert Louis Stevenson (1915), who was a long-term resident of Apia (excerpt [2] below):

Then the storm broke. There were thirteen unlucky vessels afloat in Apia Bay when the sun rose. When it set, there were none. Twelve were sunk or grounded. One, the British warship "Calliope", had steamed out of the harbour mouth against the storm. If the battle had been fought, the loss of shipping could not have been greater. . . . Of the eighty Germans on the "Eber", only four were saved. When the news of the happenings reached Europe and America, the horror of it banished all thoughts of war. [1]

Thus in what seemed the very article of war, and within a single day, the sword arm of each of the two angry powers was broken; their formidable ships reduced to junk; the disciplined hundreds to a hoard of castaways. The hurricane of March 16 . . . directly and at once brought about the congress and treaty of Berlin; indirectly . . . it founded the modern navy of the United States. Coming years and other historians will declare the influence of that navy. [2]

At this point it is helpful to give a generalised definition for tropical cyclones, to avoid the possibility of any confusion with other types of climatic phenomena. Meteorology describes a tropical cyclone as a particularly violent type of migratory, non-frontal revolving storm, with low central barometric pressure, that forms over tropical waters. Because cyclones have steep pressure gradients, they incite phenomenal winds that drive enormous storm waves, and produce heavy condensation and torrential precipitation (Garbell 1947). The origin of the term 'cyclone' is based on the Greek word *κυκλοζ* ('kyklos'), meaning circle or coil, indicating the characteristically inward-spiralling flow of air towards the centre of the storm. A distinguishing feature of cyclones is their small, nearly circular area of clear and calm weather in the middle of the system, known as the *eye*.

Although these types of revolving storms are confined to specific regions across the globe, a variety of names exist according to the ocean basin within which they form. In the western North Atlantic and the Caribbean they are known as *hurricanes*; in the western North Pacific and China Sea as *typhoons*; in the western South Pacific and Indian Ocean they are called *tropical* *cyclones*. Throughout this book the term 'tropical cyclone' (or more simply 'cyclone') will normally be employed, often abbreviated to 'TC' where 'Tropical Cyclone' forms part of the name of an individual storm, for example 'TC Nancy'. The term 'storm' will also be used interchangeably with 'tropical cyclone', because other types of storms are not discussed.

The magnitude of the effects produced by tropical cyclones on the physical environments of islands in the South Pacific is a function of two sets of variables:

1. the severity of storms,
2. the sensitivity of the islands affected.

Storm severity is a wide-ranging term, used here to encompass all those variables related to the climatological characteristics and behaviour of tropical cyclone events. This includes storm frequency, intensity, speed of movement, longevity, size, proximity to islands, and so on. Island sensitivity, on the other hand, concerns the nature of different island types in the South Pacific, and how features of their physical geography influence and condition island responses to the various geomorphic and hydrological processes that are triggered during storm events. Owing to the great diversity of island types in the tropical South Pacific, geomorphic responses to tropical cyclones vary enormously. For example, the interior of volcanic islands with steep slopes and rugged terrain are sensitive to disturbances associated with slope and fluvial geomorphology, such as mass movements and river channel erosion. In comparison, low-lying coral islands with little relief built on atoll-reef foundations are sensitive to changes in their coastal geomorphology, for example reef damage and beach erosion.

The above division of the factors influencing tropical cyclone impacts on the physical geography of islands into the two groups given, namely storm severity and island sensitivity, is a simplistic model. Yet it does have the advantage that it provides a convenient framework for this book. Thus:

Part I (Chapters 1–6) explores and describes the climatology of tropical cyclones in the South Pacific.

Part II (Chapters 7–10) illustrates the physical geographic processes and landform changes that are the direct or indirect result of cyclone effects on islands.

1.2 The Study Area

The study area for this book is the tropical South Pacific Ocean. This is an enormous expanse of water, stretching across over 20 million square kilometres. Within this area lie thousands of islands belonging to more than 15 developing island nations, states and territories. From west to east these include Solomon Islands, New Caledonia, Vanuatu, Nauru, Kiribati, Tuvalu, Fiji, Wallis and Futuna, Tonga, Tokelau, Samoa, American Samoa, Niue, Cook Islands and French Polynesia, as shown in Fig. 1.1.

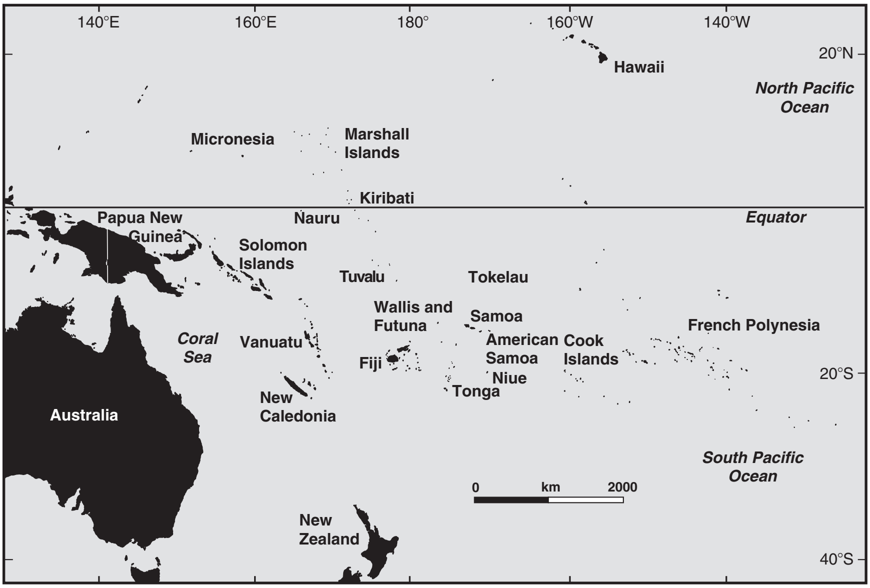

FIG. 1.1. The South Pacific Islands.

Conveniently, most of the study area falls under the responsibility of the Fiji Meteorological Service (FMS) for recording and archiving tropical cyclone activity. The FMS area of coverage extends from the Equator to Latitude 25°S and from Longitude 160°E to 120°W (Fig. 1.2). The FMS functions as a department under the Government of the Republic of the Fiji Islands (Fiji Meteorological Service 2006). The FMS headquarters is located in the compound of Nadi International Airport, in the town of Nadi on the western coast of Viti Levu island. Viti Levu is the main island in the Fiji group.

The FMS has two main output divisions, namely the Forecast Services Division and the Climate Services Division. The Forecast Services Division operates the Regional Specialized Meteorological Centre–Nadi Tropical Cyclone Centre (RSMC-Nadi TCC). The authority to operate as the RSMC for the tropical South Pacific region is granted by the World Meteorological Organization. The RSMC-Nadi is one of six Regional Specialized Meteorological Centres and an additional five Tropical Cyclone Warning Centres around the world. The areas of control and boundaries of these centres are shown in Fig. 1.2. The RSMC-Nadi provides weather forecasts, issues tropical cyclone warnings and other severe weather bulletins, and gives advisory meteorological information for the region. The RSMC-Nadi has the responsibility of naming and monitoring all tropical cyclones originating or moving into its region, and to issue warnings for the safety of all communities, including marine and aviation users.

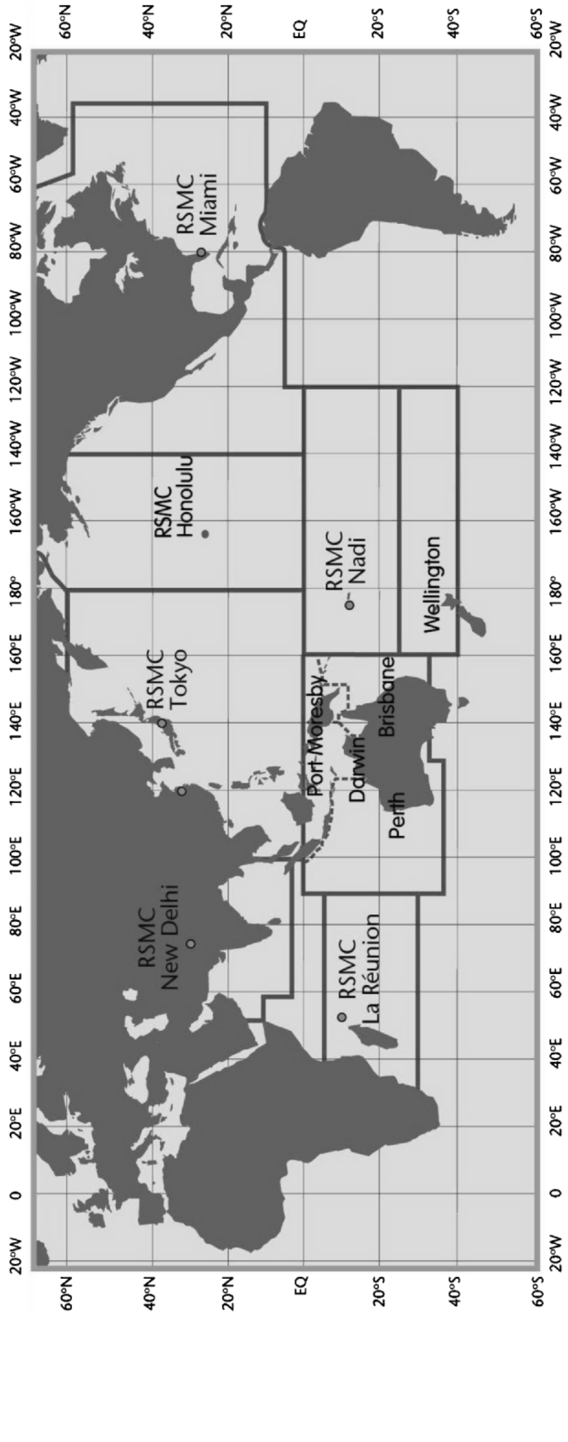

FIG. 1.2. Location of Regional Specialized Meteorological Centres (RSMC) and Tropical Cyclone Warning Centres (named), showing the geographical extent and boundaries of their regions of responsibility. Source: World Meteorological Organization WMO (2006a).

The second division of the FMS, the Climate Services Division, provides climate expertise and consultative services. It also serves as the national repository for climatological data and regional tropical cyclone activity records. The Climate Services Division of the FMS maintains the most comprehensive archive of historical tropical cyclone events and associated meteorological information (weather charts, satellite imagery, track data, wind speeds, barometric pressures, etc.) for the South Pacific region. It is this archive which has been utilised for the investigation of tropical cyclone characteristics presented in this book.

1.3 Regional Climatic Influences

Before describing the climatology and behaviour of tropical cyclones in the South Pacific, it is important to present an outline of some of the major controls on regional climatology. This provides a necessary yardstick for comparison between normal patterns and extreme events, and helps to explain many aspects of tropical cyclone formation in later chapters. Meteorological characteristics of the region are not described here, but for those interested in weather patterns and detailed meteorology of various island groups in the study area, readers are directed to several of the internet Web sites of the national climate service providers in the South Pacific.[1]

1.3.1 The Southeast Trade Winds

Most of the western region of the tropical South Pacific benefits from the Southeast Trade Winds. These are produced by the effect of Coriolis deflection on surface air drawn towards the low pressure region at the Equator, called the Equatorial Trough. The Coriolis deflection of winds, which is to the left in the Southern Hemisphere, is caused by the Earth's rotation. The Southeast Trade Winds are persistent for most of the year, although they tend to be weaker in the summer season (from November to April), and stronger in winter (from May to October).

As the Southeast Trade Winds blow across vast stretches of open ocean, they collect large amounts of moisture derived from evaporation at the sea surface. Vertical mixing of this moist air may give rise to some condensation and clouds. In general though, trade wind weather over the atolls and the other low islands of southwest Pacific is clear and fresh. This is because the lack of significant relief on low islands means that no clouds form by the process of orographic lifting, so rainfall is mainly convectional and frontal. This situation

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[1] For Fiji: http://www.met.gov.fj; for French Polynesia: http://www.meteo.pf; for New Caledonia http://www.meteo.nc; for New Zealand: http://www.niwascience.co.nz; for Samoa: http://www.meteorology.gov.ws; for Tonga: http://www.mca.gov.to/met; for Vanuatu: http://www.meteo.vu.

is in marked contrast to high volcanic islands, where the orographic effect is the most important rainfall-generating mechanism on the windward southeast sides of islands facing into the Trade Winds. This can result in big geographical variation in annual rainfall totals across many high islands, and local people often refer to the 'wet' and 'dry' sides of their islands.

The interaction of volcanic relief and the Southeast Trade Winds on rainfall distribution is illustrated in Table 1.1 for Viti Levu island in Fiji. Suva city on the southeast coast of Viti Levu lies on the wet side of the island, and receives almost 3,000 mm of rain annually during 240 rain days. Lautoka city on the northwest coast enjoys a drier location in the lee of the volcanic highlands in the interior of the island. Lautoka therefore receives 1,903 mm of rain a year in less than half the number of rain days experienced by Suva. Relative humidity is correspondingly higher in Suva than in Lautoka, and as might be expected, this has an inverse effect on daily sunshine hours for the two cities. Isohyets extrapolated across entire Viti Levu are seen in Fig. 1.3, showing that the wettest part of the island is the central volcanic highlands.

TABLE 1.1. Long-term climatic averages for two coastal sites in Fiji. Suva and Lautoka cities are located on the southeast windward and northwest leeward coasts of Viti Levu Island, respectively.

Suva City												
Station location: Laucala Bay; Latitude 18°09S Longitude 178°27E; Elevation: 6 m												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall in millimetres (1942–2002)												
343	293	373	366	245	168	142	148	191	206	254	269	2998
Number of rain days (1942–2002)												
23	22	24	22	20	18	18	17	17	19	19	21	240
Relative humidity at 9 a.m. in percent (1942–2002)												
81.3	82.4	83.5	83.2	81.6	82.3	80.4	79.7	79.3	78.3	78.8	79.3	80.8
Sunshine hours per day (1926–2002)												
6.1	6.0	5.5	5.1	4.7	4.5	4.4	4.7	4.4	5.1	5.6	6.2	5.7
Lautoka City												
Station location: Lautoka Sugar Mill; Latitude 17°37S Longitude 177°27E; Elevation: 19 m												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall in millimeters (1910–2002)												
302	326	338	181	99	65	52	68	73	89	124	186	1903
Number of rain days (1910–2002)												
16	16	17	12	7	5	4	5	6	7	9	12	116
Relative humidity at 9 a.m. in percent (1957–2002)												
74.3	76.5	77.0	75.5	74.1	74.2	71.7	69.2	68.7	68.6	69.0	70.3	72.4
Sunshine hours per day (1957–2002)												
6.7	6.7	6.8	6.4	6.9	6.8	7.1	7.5	7.0	7.5	7.4	7.4	7.0

They are separated by volcanic mountains that rise in the centre of the island to over 1,300 m above the sea level. Data Source: Fiji Meteorological Service.

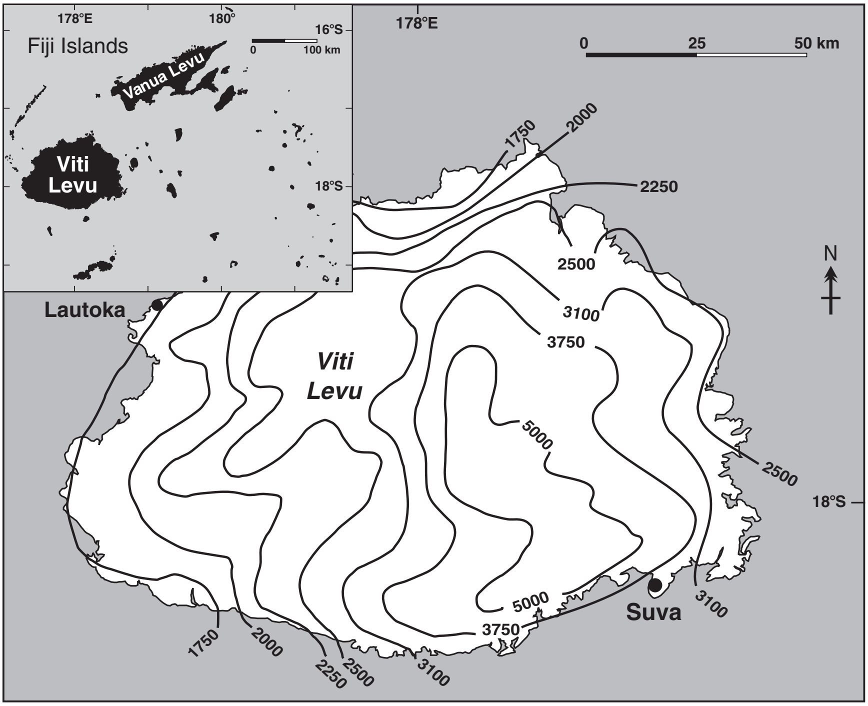

FIG. 1.3. Isohyets of annual precipitation on Viti Levu, the main island in Fiji, illustrating the difference in rainfall between the wet windward and drier leeward sides of the Island. The pattern is produced by the orographic effect of the high interior volcanic relief on the dominant Southeast Trade Winds. Source: Fiji Meteorological Service.

1.3.2 The South Pacific Convergence Zone

The second main regional climatic influence is the South Pacific Convergence Zone (SPCZ). This is a wide band of low pressure with an approximate northwest to southeast orientation over the southwest Pacific, extending diagonally from near Solomon Islands, across to Samoa, the Cook Islands and beyond (Salinger *et al*. 1995). The SPCZ marks the boundary between the Southeast Trade Winds and the Divergent Easterly Winds farther to the northeast, produced by a high pressure system that sits over the eastern part of the southwest Pacific on a semi-permanent basis. Since the SPCZ is a low-pressure trough, it is associated with cloud and rain.

An important feature of the South Pacific Convergence Zone is its seasonal migration (Hay *et al*. 1993, Vincent 1994). It generally lies equatorwards, i.e. to the north of its average position, in mid-winter (July), and moves to occupy a more southerly position by mid-summer (January) (Fig. 1.4). During the summer, the SPCZ tends to be better defined and have

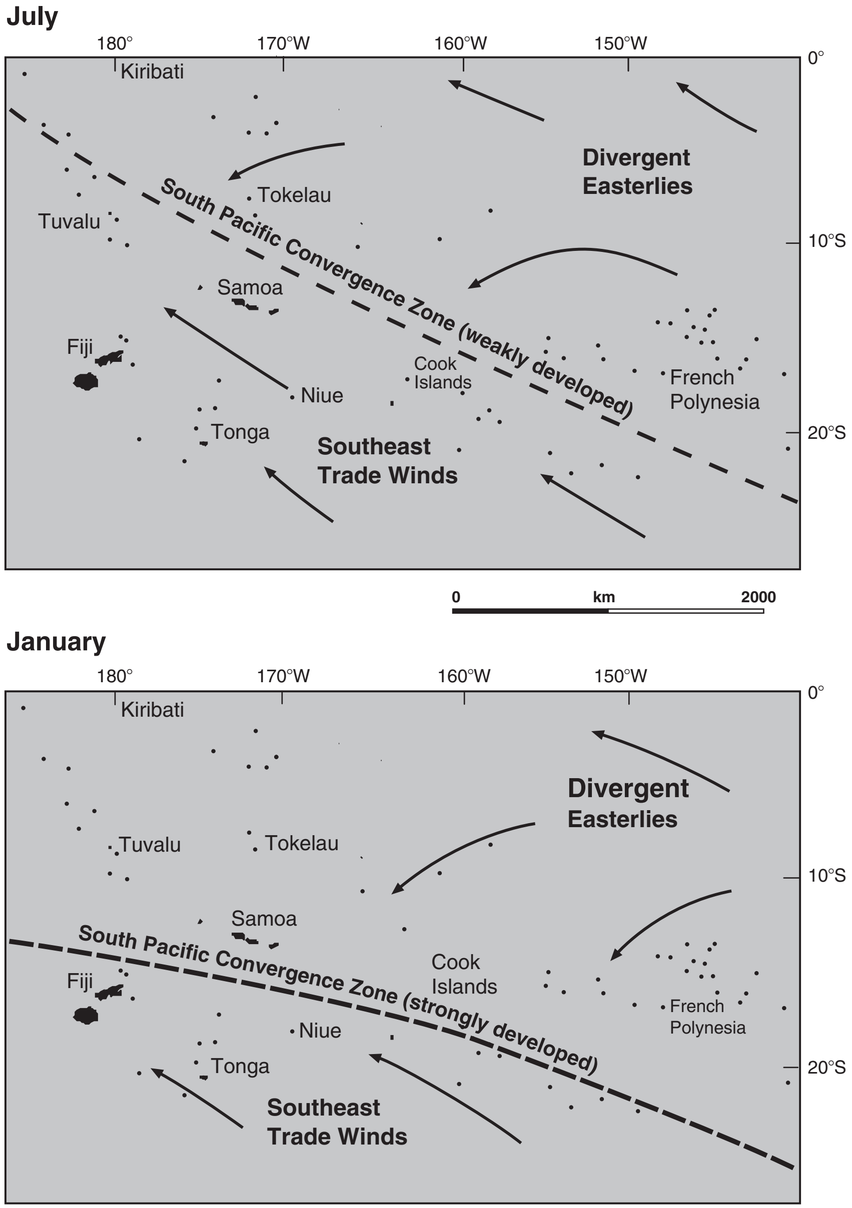

FIG. 1.4. Seasonal migration of the South Pacific Convergence Zone (SPCZ) from mid-summer (January) to mid-winter (July). Adapted from Nunn (1994).

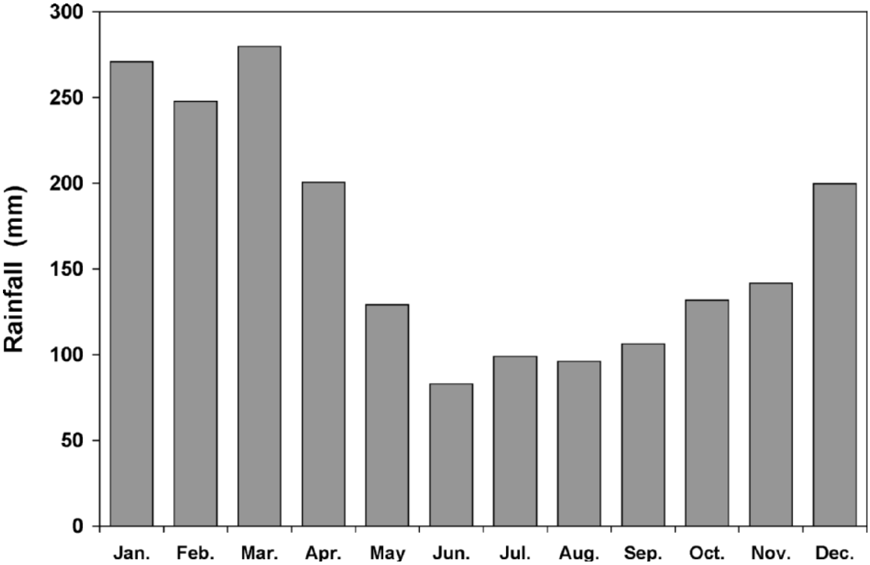

FIG. 1.5. Long-term (1905–1999) monthly rainfall for Alofi, the capital of Niue. Data Source: Niue Meteorological Office.

more active convergence, often producing thick stratiform and cumulus clouds, and associated showery weather. Sometimes very large cumulonimbus towers of cloud may form, bringing thunderstorms and intense rain.

The seasonal north-to-south shifting and alternate weak and strong activity of the SPCZ are reflected in the distinctly seasonal pattern of the annual rainfall across the islands of the South Pacific. A wet–dry seasonality is experienced by all tropical islands in the southwest Pacific. For example, on Niue island, approximately 67% of the total 1,992 mm of rainfall in a year arrives in the summer wet season when the strong SPCZ lies nearby, and the remaining 33% arrives during the winter dry season when the SPCZ weakens and moves away (Terry 2004a). Monthly rainfall for Alofi, the capital of Niue, is shown in Fig. 1.5.

1.3.3 The El Niño-Southern Oscillation

A third major control on climate of the South Pacific is the El Niño-Southern Oscillation (ENSO). At the inter-annual timescale, the ENSO phenomenon is our planet's most powerful climatic influence (Hilton 1998). Under normal conditions, low pressure at the Equatorial Trough and high pressure in the eastern Pacific establish a pressure gradient that keeps the Southeast Trade Winds blowing strongly. The combination of the Southeast Trades and the South Equatorial Ocean Current flowing east to west below the Equator allows the build-up of a very large body of warm water in the western equatorial Pacific, centred north of Australia and New Guinea.

At intervals of about 5–7 years, for reasons climatologists and oceanographers do not yet fully understand, there is a major disturbance to the coupled Pacific ocean–atmosphere system. This is called a positive ENSO anomaly or El Niño event[2] and can last for more than a year. An El Niño

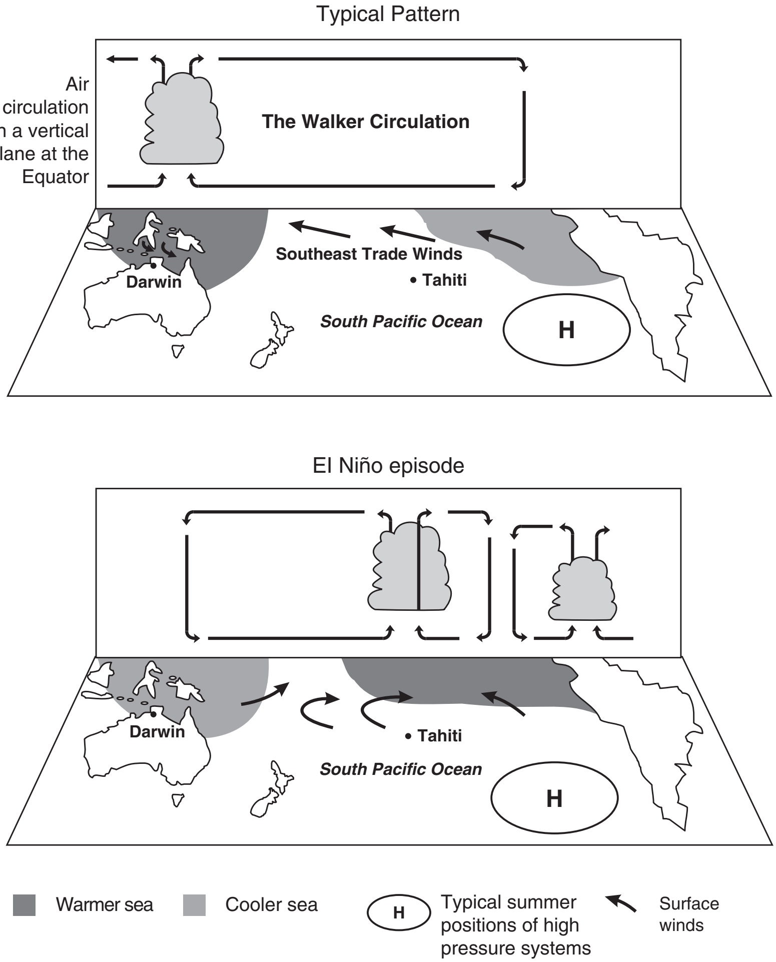

FIG. 1.6. Changes in atmospheric circulation, sea temperatures and surface winds from normal to El Niño conditions across the South Pacific Ocean. Source: Australian Bureau of Meteorology.

[2] El Niño refers properly to the oceanic component of the El Niño-Southern Oscillation system, the Southern Oscillation refers to the atmospheric component and ENSO refers to the coupled ocean–atmosphere system. In practice, El Niño is sometimes used to refer to the entire system (NOAA 2006a).