Miksad, R. (1976) An omni-directional static pressure probe. *J. Meteorol. Soc. Jpn.*, **15**, Nov. 1976

Strangeways, I. C. (2002) Back to basics: The 'met. enclosure': Part 8(a) – Barometric pressure, mercury barometers. *Weather*, **57**, pp. 132–139

Sutton, G. (1965) Admiral FitzRoy and the storm glass. *Weather*, **20**, pp. 270–271

United States Weather Bureau (1963) *Manual of barometry (WBAN), 1.* US Government Printing Office, Washington, DC

World Meteorological Organization (1996) *Guide to meteorological instruments and methods of observation*, sixth edition. WMO No. 8. Geneva

Correspondence to: Dr I. C. Strangeways, Terra-Data, PO Box 48, Wallingford, Oxon. OX10 0JJ.

El Niño – causes, consequences and solutions*

Christine Coghlan
Moreton, Wirral

Over the last 30 years, the El Niño phenomenon has received substantial attention throughout the world, primarily because of its severe global impacts. The event is now portrayed regularly worldwide in newspapers, magazines, and on television news and other programmes, and it is thus becoming increasingly familiar to the general public.

Scientists have been baffled by the phenomenon for many decades. Research attempts have uncovered many aspects of the events such as the physical characteristics, and its dynamic effects which are felt all over the globe. The El Niño occurrence is now seen as one of the most prominent sources of inter-annual variations in weather and climate around the world (Glantz *et al.* 1991). The development of our understanding has led to the term 'El Niño' being directly related to, and a consequence of, the coupling of the tropical atmosphere and ocean. It is only in the last few decades that there has been a greater focus on the warm and cold phases of the phenomenon – El Niño and La Niña, respectively.

What is El Niño?

El Niño translates as 'the Christ child'. Studies show that El Niño was first brought to notice over 100 years ago. However, documentary evidence from local South American mariners and fishermen indicates that the El Niño phenomenon dates back to at least the early 1500s. South American west coast fishermen used the term 'El Niño' to define the annual weak warm current that ran southwards along the coast of Peru and Ecuador around Christmas time (Glantz *et al.* 1991).

During the latter years of the nineteenth century, further scientific exposure of El Niño developed, and studies in the first half of the twentieth century showed strong links of local flooding rains in Peru with warm episodes. Schott was the first to use the term 'El Niño' for the wider oceanic occurrence of warm waters advected southward from around the Galapagos Islands and, during 1957/58, for the first time, observations were made of large-scale oceanic warming extending across the equatorial Pacific beyond the dateline in connection with an El Niño event during that period (Allan *et al.* 1996).

The term 'La Niña' became more renowned in the latter decade or two of the twentieth century. Translating as 'the girl child', the term is known today for the opposite oceanic conditions to El Niño.

* This was the winning entry in *Weather*'s essay competition for 2001.

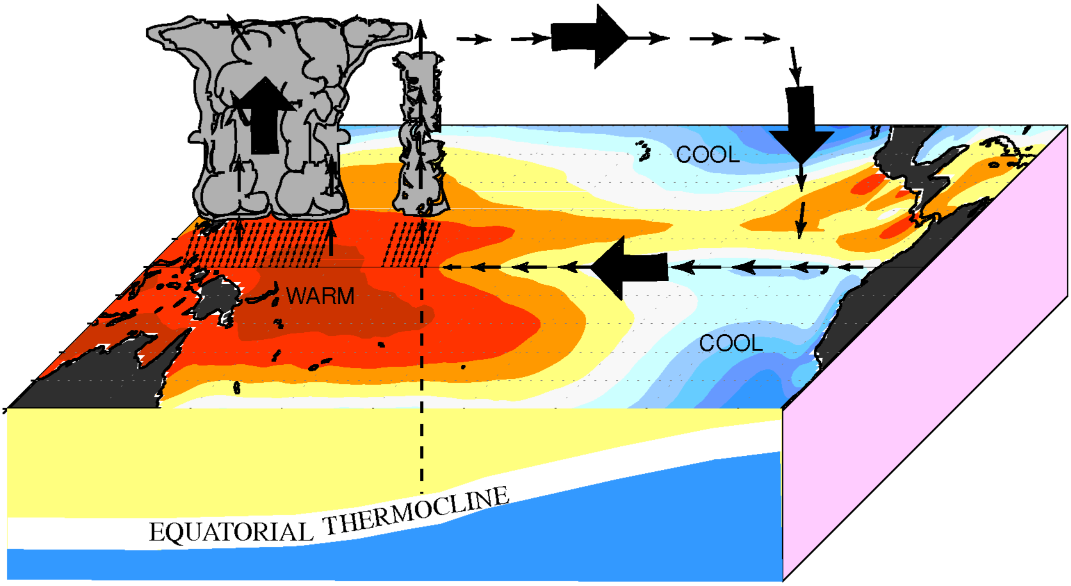

Fig. 1 December–February normal conditions (from NOAA*)*

Normal conditions

Throughout the year the Pacific Ocean surface is warmest in the west and coldest in the east. The greatest range in temperature occurs during September and October when temperatures in the western Pacific reach their annual maximum. Temperatures across the central Pacific then normally start to increase during December and peak in April as the intensity of the upwelling decreases.

Ocean surface temperatures across the tropical Pacific contribute significantly to the observed patterns of tropical rainfall and tropical thunderstorm activity. As Fig. 1 shows, the heaviest rainfall is typically observed across Indonesia and western parts of the tropical Pacific, with least rainfall occurring across the eastern equatorial Pacific. The mean patterns of sea surface temperature and equatorial rainfall are accompanied by low-level easterly winds and upper-level westerly winds across the tropical Pacific. Figure 1 illustrates how, over the western tropical Pacific and Indonesia, this wind pattern is associated with low air pressure and ascending motion, while over the eastern Pacific it is accompanied by high pressure and descending motion. Collectively, these conditions reflect the equatorial Walker circulation which is a primary large-scale circulation feature across the Pacific.

The subsurface ocean structure is characterised by a deep layer of warm water in the western tropical Pacific, and by a comparatively shallow layer of warm water in the eastern Pacific, as Fig. 1 shows. This warm water is separated from the cold, deep waters by the oceanic thermocline, which is normally deepest in the west and slopes upward toward the surface further east. The resulting east–west variations in mean upper-ocean temperatures, and hence densities, result in east–west variations in sea-level height, which is higher in the west than in the east. Figure 2 shows this pattern for the winter of 1995/96 (normal conditions). Data are taken from the joint National Aeronautics and Space Administration/Centre National d'Etudes Spatiales satellite altimeter, Topex-Poseidon. Sea-level deviations were calculated with respect to the 3-year period 1993–96.

Pacific Ocean temperatures, tropical rainfall and vertical motion patterns greatly affect the distribution of atmospheric heating across the tropical and subtropical Pacific. Normally, the strongest heating and highest air temperatures coincide with the warmest ocean waters and heaviest rainfall. This atmospheric heating helps to determine the overall north–south temperature differences in both hemispheres, which significantly affect the strength and location of the jet streams. These tend to be most

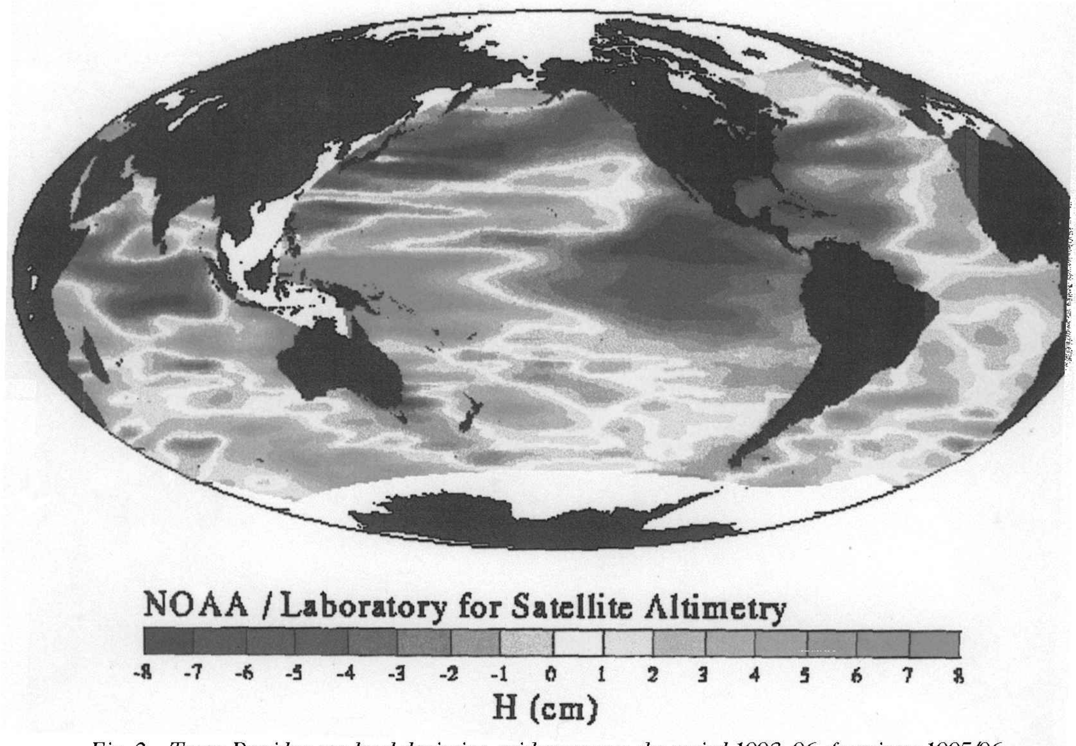

Fig. 2 Topex-Poseidon sea-level deviation, with respect to the period 1993–96, for winter 1995/96

pronounced during the respective hemisphere's winter season, when both the location and eastward extent of the jets exhibit a strong relationship to the pattern of tropical heating. These jet streams are then a major factor in controlling the winter weather patterns and storm tracks in the middle latitudes over both North and South America. La Niña conditions are essentially extreme forms of 'normal' conditions.

El Niño conditions

Defining what is an El Niño event is not straightforward, as each has its own characteristics and strength while exhibiting the general properties of El Niño. During an El Niño event, the low-level trade winds relax in the central and western Pacific, leading to a depression of the thermocline in the eastern Pacific and an elevation of the thermocline in the west. The result is a rise in sea surface temperatures as upwelling decreases (National Oceanic and Atmospheric Administration (NOAA) 1998).

Figure 3 shows that during the phase associated with El Niño, anomalous cloudiness and convection are created by the band of warm water that develops in the central Pacific. Atmospheric pressure falls in the eastern Pacific, whilst above normal atmospheric pressure is evident in the Australasian region. Rainfall accompanies the warm water eastward, and tropical cyclone tracks and genesis regions tend to be displaced to the north-east of their average locations in the south-west Pacific (Allan *et al.* 1996). As a result, associated flooding occurs in Peru and drought in Indonesia and Australia. Because of the wind changes the sea-level drops in the west and rises in the east. Figure 4 shows the Topex-Poseidon sea-level deviations for the winter of 1997/98 when El Niño conditions were present in the Pacific.

The eastward displacement of the atmospheric heat source overlying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific. Table 1 provides a list of El Niño events from 1871 to 2000.

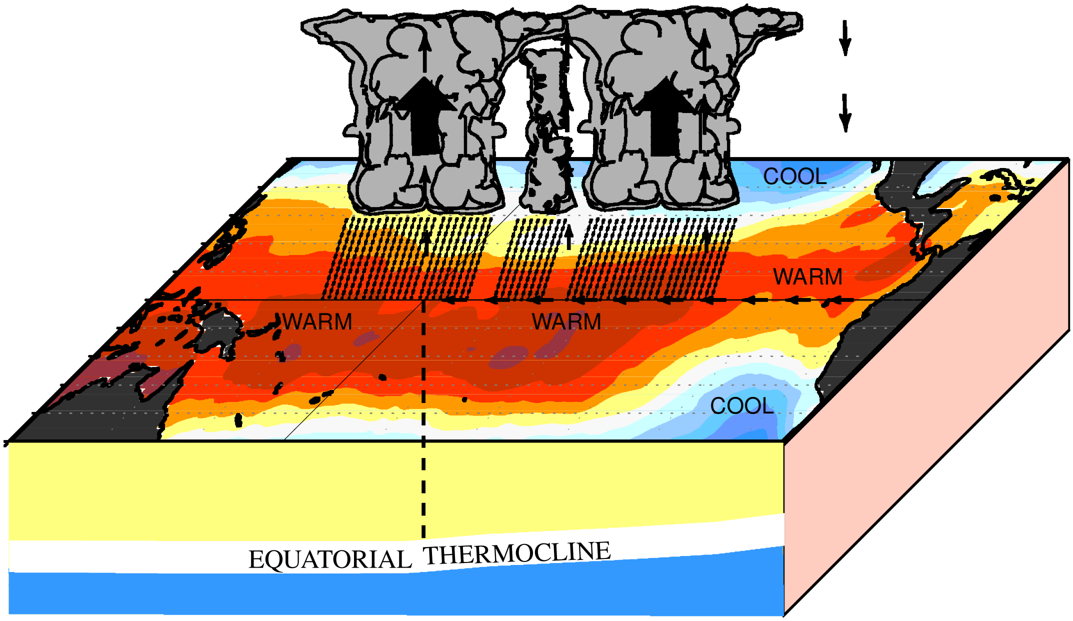

Fig. 3 *December–February El Niño conditions (from* NOAA*)*

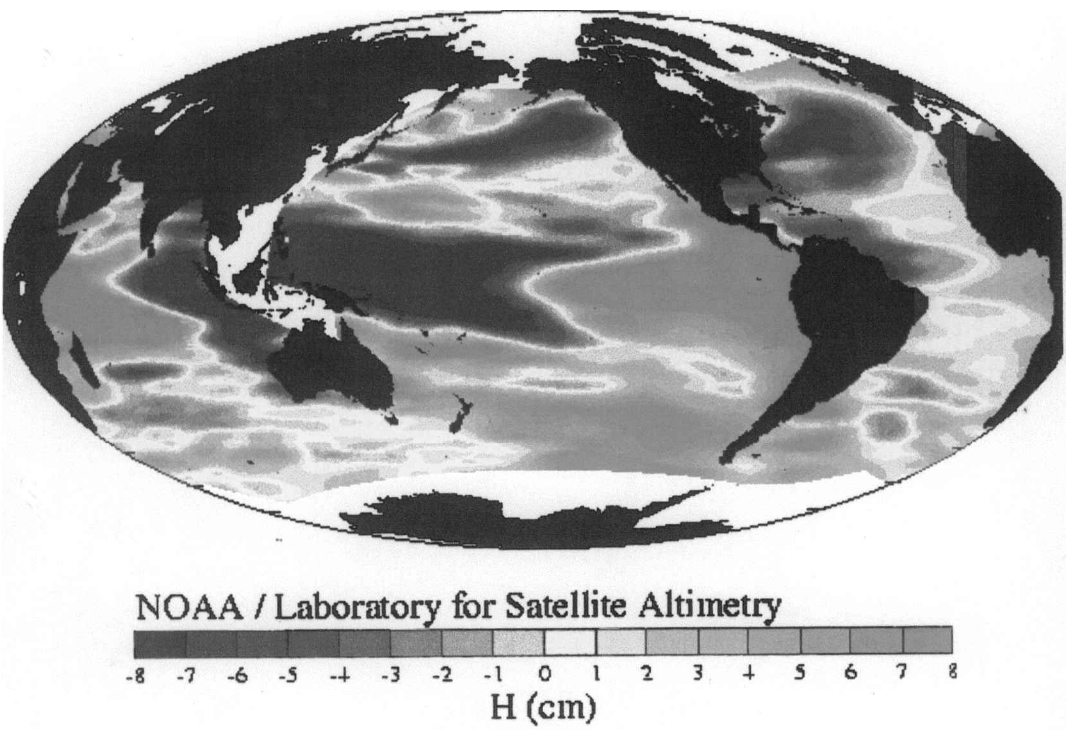

Fig. 4 *Topex-Poseidon sea-level deviation, with respect to the period 1993-96, for winter 1997/98*

Table 1 Years of occurrence of warm (El Niño) events based on a 1 degC anomaly in sea surface temperature (from information supplied by the Met Office)

Warm event years	
1877/78	1939/40
1880	1941
1885	1957/58
1888/89	1963
1891	1965/66
1896/97	1969
1899/1900	1972/73
1902/03	1976/77
1905/06	1982/83
1911/12	1986/87
1914/15	1991/92
1918/19	1994/95
1925/26	1997/98
1930/31	

Consequences of El Niño

There has been a growing interest in using El Niño events in the equatorial Pacific Ocean for forecasting climate anomalies in different parts of the globe. Such linkages, called climatic teleconnections, are used by some countries to forecast impending weather-related problems and their impacts. El Niño events are now acknowledged to have global implications. During an El Niño event the regions of warm, moist air convergence are displaced. This change is transmitted round the world through upper-atmospheric processes leading to widespread shifts in the normal patterns of rain, temperature and wind. However, it is important to recognise that changes due to El Niño can still be swamped by other local events which are contrary to the expected El Niño signal.

During strong El Niño phases, the displacement of warm water in the Pacific (shown in Fig. 3) causes anomalous convective activity over the central eastern Pacific, central western equatorial Indian Ocean, and off/near the Atlantic equatorial coast of Africa and north-western South America (Allan *et al.* 1996). Surface winds converge on to these regions bringing towering cumulus clouds and abundant rainfall. In contrast, over Indonesia, Australia, India and south-east Africa, drought conditions are usually experienced. The rainfall deficiencies vary in their timing.

The major El Niño event of 1982/83 caused severe drought over Indonesia. This affected the dry-season crop, and outbreaks of cholera related to the effect of drought on water supplies caused hundreds of deaths (Glantz *et al.* 1991). The skies over Indonesia and Malaysia were blackened during the recent 1997/98 event as smoke from forest fires swept across the region.

Due to the shift in the areas where there is heavy rainfall (called convergence zones), combined with low-level convergence of windflow, particularly evident through anomalous winds in the tropics, there is a compensatory divergence of upper-atmospheric winds away from the displaced convective regions (Allan *et al.* 1996). As a consequence, the jet streams tend to be displaced equatorward causing unusual weather patterns in the extratropics (Philander 1998).

The main impact of El Niño in the extratropics is felt during the winter months. During the last warm event of 1997/98, ice storms swept through eastern Canada during January 1998, forcing a trough of cold arctic air to cover the American east coast while a ridge of warm air moved northward as far as southern Ontario and Quebec. The unusually warmer weather in Canada caused temperatures to be high enough that freezing rain fell instead of snow, whilst in California the shift caused heavy rainfall.

In monsoon regions, such as India, it has long been recognised that with the influence of El Niño variations in the monsoon rains occur, usually failing during strong El Niño years. Tropical cyclone activity is also affected by El Niño. In general, warm episodes are characterised by an increased number of tropical storms and hurricanes in the eastern Pacific and a decrease in the Gulf of Mexico and the Carribean Sea. The Australian/south-west Pacific shows a pronounced east–west shift of tropical cyclone activity with fewer tropical cyclones between 145 and 165°E and more from 165°E eastward across the South Pacific. There is also a tendency for tropical cyclones to originate a bit closer to the equator (NOAA 1998). In the north-west Pacific, Lander (1994) found that there was a reduction in the number of tropical storms plus typhoons during the El Niño years. He also found that the genesis region for tropical cyclones in the north-west Pacific shifts eastward during the warm phase.

There are regions where El Niño has no clear effect. Some regions may be far from the Pacific, or may have strong variability that is not related to El Niño. Both of these factors apply to Europe. A number of studies have been made linking possible El Niño effects on European climate, including those by Fraedrich and Müller (1992) and Moron and Ward (1998). There is a tendency during the winter season for low surface pressure occurring over western and central Europe to cause positive precipitation anomalies. There is an opposite tendency over northern Europe. The paths of storms travelling from the Atlantic sector to cross Europe may be shifted northward by El Niño (Fraedrich and Müller 1992). Figure 5 summarises the impacts usually caused by El Niño events.

Solutions

El Niño is a natural part of the complex ocean–atmosphere system. The phenomenon appears to be subject to self-sustaining periods and can therefore be predicted relatively easily. However, at times, random disturbances can excite it, such as westerly wind bursts, and prediction is not so straightforward, as scientists found out during the 1997/98 event.

Scientists use mathematical models to predict El Niño events. The most complete models aim to represent as wide a range of physical processes as possible. The results thus far, though by no means perfect, give a better indication of the climatic conditions that will prevail during the next one or two seasons. The

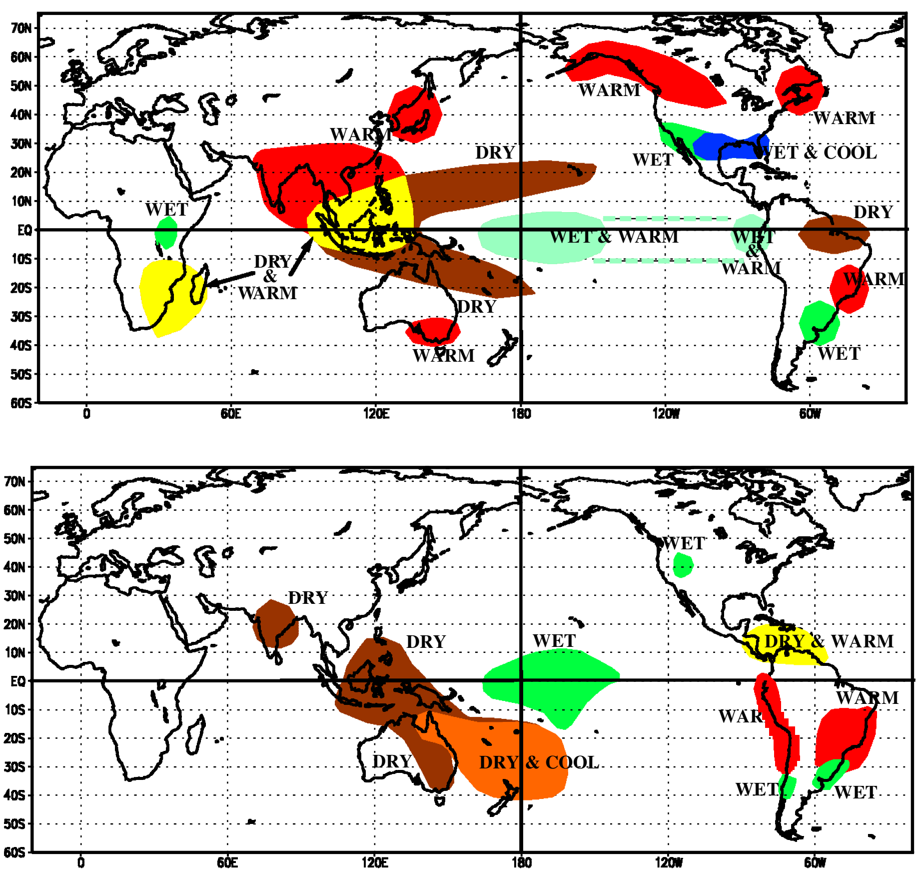

Fig. 5 Warm episode relationships for December–February (above) and June–August (below) (from NOAA*)*

progress within the last decade has been substantial. Scientists and governments in many countries are working together to design and build a global system for (i) observing the tropical oceans, (ii) predicting El Niño and other irregular climate rhythms, and (iii) making routine climate predictions readily available to those who have need of them for planning purposes (NOAA 1998).

We are still learning what an El Niño event can do. No two events are exactly alike so that their impact on worldwide ecologies and economies will also be dissimilar. Caution must be used in attributing any particular anomaly or impact to a specific El Niño because climate-related anomalies can also result from a variety of local and regional conditions, even in the absence of El Niño events. The atmosphere exhibits considerable variability on time-scales ranging from days to seasons to years. This variability often reflects little more than the normal chaotic behaviour of our atmosphere.

References

Allan, R., Lindesay, J. and Parker, D. (1996) *El Niño–Southern Oscillation and climate variability.* CSIRO, Australia

Fraedrich, K. and Müller, K. (1992) Climate anomalies in Europe associated with ENSO extremes. *Int. J. Climatol.*, **12**, pp. 25–31

Glantz, M. H., Katz, R. W. and Nicholls, N. (1991) *Teleconnections linking worldwide climate anomalies.* Cambridge University Press

Lander, M. A. (1994) An exploratory analysis of the relationship between the tropical storm formation in the western North Pacific and ENSO. *Mon. Wea. Rev.*, **122**, pp. 636–651

Moron, V. and Ward, M. N. (1998) ENSO teleconnections with climate variability in the European and African sectors. *Weather*, **53**, pp. 287–295

NOAA (1998) http://www.cdc.noaa.gov/ENSO/

Philander, G. (1998) Learning from El Niño. *Weather*, **53**, pp. 270–274

Correspondence to: Miss C. Coghlan, 20 Cartmel Drive, Moreton, Wirral CH46 0TE.

Spatial distribution of rainfall seasonality in Greece

E. A. Kanellopoulou
Department of Geography and Climatology, University of Athens

Data and analysis

Rainfall regimes are of great interest (Ramage 1971; Jackson 1977; Nieuwolt 1974) because knowledge of the rainfall amount in a region defines the degree of vegetation and, generally speaking, the quality of life itself. The seasonal characteristics of rainfall are the parameters which are taken into account for the Köppen classification (Köppen and Geiger 1936), while potential evapotranspiration compared with rainfall is also used for climate classification (Thornthwaite 1948; Penman 1963).

The relative seasonality of rainfall represents the degree of variability in monthly rainfall throughout the year (Walsh and Lawer 1981). In order to define the seasonal contrasts, the Seasonality Index (SI), which is a function of mean monthly and annual rainfall, is assessed using the following formula:

$$SI = \left(\frac{1}{\overline{R}}\right) \sum_{n=1}^{12} \left| \overline{x}_n - \frac{\overline{R}}{12} \right|$$

where $\overline{x}_n$ is the mean rainfall of month n and $\overline{R}$ is the mean annual rainfall. Theoretically, the SI can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in one month).