



Climate Variability and Climate Change Assessment for the Seychelles

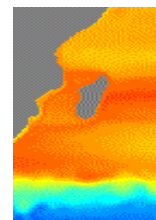
Denis Chang-Seng



Intense tropical cyclone 'Banda' impact on Providence Island, Mahe Seychelles, Photo: Adrian Stewart, 2006

Prepared for the Seychelles Second National Communication (SNC) Under the United Nations Framework Convention on Climate Change (UNFCCC), and with the Guidance of the National Climate Change Committee (NCCC)

Ministry of Environment and Natural Resources
Republic of Seychelles
October 2007



Acknowledgements

Climate Center, National Meteorological Services
Marcel Belmont and Gemma Meriton for climate data

Reviewers

Theodore Marguerite, Antoine Marie Moustache

© All graphs presented were sourced from the main author, unless specified within the figures

Seychelles' National Climate Change Committee (NCCC)

Denis Chang-Seng, 2007

Contents

1.0	Introduction.....	1
2.0	Observed Climate Variability & Climate Change.....	4
2.1	Climate of the Seychelles.....	4
2.2	Changes in Air Temperature.....	5
2.3	Changes in Sea Surface Temperature (SST)	10
2.3.1	Temporal and Spatial Changes in SST	
2.4	Changes in Rainfall.....	13
2.4.1	Temporal Changes in Rainfall	
2.4.2	Spatial Changes in Rainfall	
2.4.3	Longer Temporal Changes in Rainfall	
2.5	Change in Sea Level.....	21
2.5.1	Temporal Changes in Sea Level	
2.5.2	Spatial Changes in Sea Level	
2.6	Changes in Tropical Cyclone.....	27
2.6.1	Temporal Changes in Tropical Cyclone	
2.6.2	Spatial Changes in Tropical Cyclone	
2.7	Impact of ENSO	37
2.7.1	ENSO and Air Temperature	
2.7.2	ENSO, SST and Sea Level	
2.7.3	ENSO and Rainfall	
2.7.4	ENSO and Tropical cyclone	
3.0	Paleo-Climite Changes.....	46
4.0	Summary.....	49

List of Figures

Figure 2.2.1: DJF, JJA and annual maximum temperature anomalies	14
Figure 2.2.2: DJF, JJA and annual minimum temperature anomalies	14
Figure 2.2.3: Standard deviation of monthly maximum temperature and its low band pass wavelet filter.....	15
Figure 2.2.4: Standard deviation of monthly minimum temperature and its low band pass wavelet filter.....	15
Figure 2.3.1: Sea surface temperature at the Seychelles International Airport	17
Figure 2.3.2: Area time series of CRU SST in the Seychelles.	17
Figure 2.3.3: Spatial change in SST from 1948-2006 relative to 1960-1990 periods.	18
Figure 2.4.1: Time series anomaly of (a) DJF, (b) JJA and (c) annual rainfall	20
Figure 2.4.2: Standard deviation of monthly rainfall at Seychelles International Airport and its low band pass wavelet filter (1.5-16 yrs)...	21
Figure 2.4.3: Annual Total Precipitation accounted for by heavy rainfall events.....	21
Figure 2.4.4: Mahe spatial rainfall variability for (a) DJF and (b) JJA seasons	22
Figure 2.4.5: Time series of raw merged rainfall anomaly for the Botanical Gardens, Port Victoria and the Seychelles International Airport	25
Figure 2.4.6: Filtered merged rainfall data at the Botanical Gardens, Port Victoria and the Airport	25
Figure 2.4.7: Wavelet power spectral analysis (>1.5 years) of merged rainfall data..	26
Figure 2.4.8: Wavelet power spectral analysis (>3 years) of merged rainfall data	26
Figure 2.5.1: Time series of Pointe Larue observed monthly sea level anomaly.	30
Figure 2.5.2: Time series of Pointe Larue monthly sea level anomaly.....	30
Figure 2.5.3: Standardized monthly sea level at Pointe Larue and its low band pass filter.....	31
Figure 2.5.4: Sea level trend in the southwest Indian Ocean.....	31
Figure 2.5.5: Standard error in sea level trend in the southwest Indian Ocean.....	32
Figure 2.5.6: Altimetry-derived sea level map for TOPEX/Poseidon observation	32
Figure 2.6.1: Tropical depression on Praslin on the 6-8th September 2002.....	37
Figure 2.6.2: Intense tropical cyclone 'Bondo' impact	38
Figure 2.6.3: Decadal distribution of the number of intense TCs by different categories.....	39

Figure 2.6.4:	Intense tropical cyclone days anomaly time series in the SWIO.....	39
Figure 2.6.5:	Wavelet power spectrum of Intense TC days time series index.....	40
Figure 2.6.6:	Time series index of tropical depression and cyclone in the SWIO.....	40
Figure 2.6.7:	Schematic diagram showing mechanisms of intense TC Days variability in the SWIO	41
Figure 2.6.8:	Historical tropical cyclone track in the Seychelles EEZ	42
Figure 2.7.1:	(a) Temporal evolution (b) co-spectral power and (c) time delay between SST and Airport maximum temperature.....	47
Figure 2.7.2:	El Nino impact on monthly rainfall during the rainy season	48
Figure 2.7.3:	El Nino impact on monthly rainfall during the dry season	49
Figure 2.7.4:	La Nina impact on monthly rainfall during the rainy season	50
Figure 2.7.5:	La Nina impact on monthly rainfall during the dry season.....	51
Figure 3.3.1:	Time series of Seychelles coral isotope.....	54
Figure 3.3.2:	Filtered Seychelles coral isotope versus CRU time series of SST.....	54

Abbreviations

INC	Initial National Communication
SNC	Second National Communication
IPCC	International Panel of Climate Change
TAR	Third Assessment Report
FAR	Fourth Assessment Report
UNFCCC	United Nation Frame Work Convention on Climate Change
NCEP	National Center of Environmental Prediction
EEZ	Exclusive Economic Zone
GLOSS	Global Sea Level Observing System
SWIO	Southwest Indian Ocean
PSMSL	Permanent Station for Monitoring Sea Level
ENSO	EL Nino Southern Oscillation
ITCZ	Inter Tropical Convergence Zone
MJO	Madden Julian Oscillation
TC	Tropical Cyclone
QBO	Quazi Biennial Oscillation)
AMO	Atlantic Multi-Decadal Oscillation
IODM	Indian Ocean Dipole Mode
SST	Sea Surface Temperature
O₁₈	Oxygen isotope
DJF	December, January and February
JJA	June, July, and August

1.0 Introduction

Seychelles as a small island country is most vulnerable to global climate variability and climate change. A single extreme abnormal hydro-meteorological event has shown to threaten the sustainable development of the Seychelles; hence the socio-economic implications are enormous and the risks are increasing in parallel with development. The Seychelles Initial National Communication (INC, 2000) for Climate Change assessed climate variability and climate change in the Seychelles. This update assessment succeeds the initial assessment principally as a result of increase in local scientific capacities, new research findings in the past few years through up to date data, more sophisticated analyses of data and in the improvements in the understanding of the climate processes, and the further exploration of uncertainty ranges. The update assessment makes an effort to link and compare local assessment to that of the IPCC TAR (Third Assessment Report, 2001) and the recent FAR (Fourth Assessment Report, 2007). The methodologies and techniques of assessment are not discussed here, but can be further consulted from the respective authors in the reference list. The report consists of four chapters ranging from the assessment of temporal and spatial temperature, rainfall, sea level, to tropical cyclone changes in the region. The effect of EL Nino Southern Oscillation (ENSO) is also brought into perspective.

One of the most important questions facing mankind in the twenty-first century is to what degree human activity is responsible for climate change; particularly temperature change. It is clear that the earth is always experiencing natural climate changes. Climate change in IPCC terminology refers *to any change in climate over time, whether due to natural variability or as a result of human activity*. This differs from the United Nations Framework Convention on Climate Change (UNFCCC) definition in which change refers to *a change in climate that is attributed directly or indirectly to human activity*.

Some of the relevant aspects of climate change are the long term ice-age or Milankovitch cycles, medium term solar fluctuations (natural cycles), the effect of

human's burning of fossil fuels (anthropogenic), the possible bias in sampling locations, and ecological and global media-political propaganda. On a scale of thousands of years, we are due for a steep drop in temperature as we enter another ice age. On the other hand, many claim that global warming is already causing excess fresh water to enter the ocean system. Consequently, the ocean conveyor belt together with the Gulf Stream which drives heat globally to keep the earth warm will decelerate and even possibly collapse. Once this occurs, this process will lead to an accelerated ice age. These scenarios could happen next year, in decades to come or not for a thousand years. Indeed, we do not know. However, the recent IPCC Fourth Assessment Report claims that the ocean conveyor belt will decelerate but not shut down altogether.

On a scale of hundreds of years, we are at or possibly past a peak of a 500-600 year cycle. This cycle appears to be associated with the rise and fall of major civilizations. On a scale of decades, present temperatures have risen very sharply and are due at least partly to solar activity. Solar cycles have become very strong and continue to defy predictions and are still becoming stronger. Temperatures on earth are correlated with the strength of sunspot cycles although we have only a relatively short record of this. However, it is well known that stronger sunspot cycles also tend to be shorter. There can be no doubt that human activity has added immensely to the amount of CO₂ in the atmosphere. The Fourth Assessment Report (FAR) strongly suggests that it is *likely* (>66%) that increases in greenhouse gas concentrations alone would have caused more warming than observed, although volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place.

Currently, models have not been able to predict how much CO₂ is absorbed by the oceans. The other problem are the uncertainties in data observations in cities where temperature change maybe only a local effect and apparent sea level changes may be caused by land subsidence. Infrequent, extreme events are often used to derive conclusions about climate change. However, such conclusions are not well founded. The other challenging problem would be the length and quality of the data. In the case of Seychelles, the climate trends are examined by analyzing various data sets

with the principal objective of identifying and establishing possible historical trends, cycles and their possible underlying causes and mechanisms.

The IPCC Fourth Assessment Report (FAR) describes the progress in understanding the human and natural drivers of climate change, observed climate change, climate processes and attributions. It succeeds the Third Assessment Report (TAR) and offers new findings for the past six years of research. The main finding of the report is that the observed widespread warming of the atmosphere and ocean, together with ice mass loss, supports the conclusion that it is *extremely unlikely* (<5%) that global climate change of the past fifty years can be explained without external forcing, and *very unlikely* (<10%) that it is not due to known natural causes alone.

It is therefore important to assess past and recent climate in order to understand and predict future climate changes through scenario modeling. Therefore, this assessment on climate variability and climate change referred here as part 1 forms the basis prior to evoking climate change scenario assessment due to anthropogenic forcing referred to as part 2 for input in the Seychelles Second National Communication (SNC) for Climate Change. The assessment should also be useful for factoring climate information into a diversity of socio-economic, environmental impact assessments (EIA), disaster and risks management activities in the Seychelles with a view to derive maximum benefits and to ensure environment - climate risks and impacts are minimized

2.0 Observed Climate Variability and Climate Change

The Chapter begins by introducing the climate of Seychelles. The assessment focuses on quality short term climate data available from the Climate Center, National Meteorological Services at Pointe Larue, Seychelles from 1972 to early 2007. It also explores, for a longer time scale, trends using merged, assimilated and paleo-climate data sets.

2.1 Climate of the Seychelles

Because of its geographical location and maritime exposure, the climate of the Seychelles is warm with mean maximum temperature of 30°C and a humidity of 75%. Average rainfall of the driest month, July, is 70 mm. July is the coolest month with a mean temperature of 26°C. The climate of the Seychelles can be divided into two main seasons, the *Northwest Monsoon* and the *Southeast Monsoon*, separated by two relatively short *Inter Monsoon* periods. The Southeast Monsoon – May to October, is a relatively drier and cooler period when the wind flow over the Seychelles is dominated by the Southeast trade winds which reach their peaks during the months of July and August. Precipitation during this period is sparse, normally light in nature and rather short-lived. Pre-Northwest Monsoon – November is characterized by the shift in wind regime from Southeast to Northwest, associated with the onset of the normal rainy season. At this time, it is relatively warm with very light winds. The *Northwest Monsoon* occurs between December and March. It is the summer season with warm temperatures but it is also the principal ‘rainy season’ with precipitation tapering off towards March. Winds are predominantly from the west to northwest but generally light. It is also the Cyclone Season over the Southwest Indian Ocean.

The equatorial regions of the study area which includes the Seychelles are well known to be indirectly affected by tropical cyclones via the intensification of the intertropical convergence zone (ITCZ) and spiral rain bands associated with cyclone passing south of the islands (Walsh, 1993). It is now well established that the spiral rain band can give rain rates equivalent to the inner structure of cyclone. In addition,

tropical cyclone by-track characterizes the preceding rainfall in the Seychelles at both event and seasonal time scales (Chang-Seng, 2005). The pre-Southeast Monsoon – April, is the calmest and warmest period of the year as the winds weaken before reversing to the southeast. It also marks the end of the rainy season as well as the approaching end of the cyclone season.

2.2 Changes in Air Temperature

In the Initial National Communication, Payet et al. (1998) analyzed average air temperature changes relative to 1972-1997 for Mahe, at the Seychelles International Airport. It was found that average near surface air temperature warming was $+0.25^{\circ}\text{C}$. It was $+0.3$ and $+0.5^{\circ}\text{C}$ in 1995 and 1997 respectively. However, the period after the 1990s had large ENSO influences. Thus, although data was not available prior to 1972 at the Seychelles International Airport, the analysis here generally adopts the 1972-1990 average as the base period to comply with the IPCC standards and to avoid the recent ENSO events ‘leaking’ into the climate base period. In addition, the assessment focuses on the air maximum and minimum temperature available only at the synoptic station at the Seychelles International Airport.

Figure 2.2.1, confirms the continued positive warming trend in the maximum temperature anomaly with rates of $+0.0149$, $+0.0032$ and $+0.0096^{\circ}\text{C}$ per year for the December, January and February (DJF), June, July, August (JJA) and the annual temperature time series respectively. The annual maximum temperature warming in the past 34 years is estimated to be $+0.33^{\circ}\text{C}$. The maximum temperature warming occurred during the summer season (DJF). The smoothed curve is a 5-point moving average showing the upward warming in the maximum temperature with respect to the 1972-1990 periods.

Figure 2.2.2, shows the positive trends and warming of $+0.0298$, $+0.0135$ and $+0.0241^{\circ}\text{C}$ per year in the DJF, JJA and annual minimum temperature respectively. The annual minimum temperature warming in the past 34 years is estimated to be $+0.82^{\circ}\text{C}$. The smooth light grey curve (5 point moving average) also indicates the

warming trend in the minimum temperature with respect to the 1972-1990 periods. The average temperature warming in the last six years is $+0.5^{\circ}\text{C}$ with a peak of $+0.7^{\circ}\text{C}$ in 2006. The minimum temperature is at least twice warmer than the maximum temperature for the DJF, JJA and annual temperature trends respectively. The minimum temperature for the cooler southeast monsoon season (JJA) is found to be warming faster than the DJF season. This result agrees with the preliminary assessment by Marguerite (2007) which decomposed extreme annual minimum temperature into low and high frequency on the basis of 3, 5 and 10 year variations. The linear trends explain 59%, 70% and 82 % of the variance respectively for the increase in extreme minimum temperature. The most significant increase has occurred during the last 10 years and it is also found that most of the warming prevailed during the dry season. Other analyses (Lajoie, 2004) have also showed that the warming trends particularly in the minimum temperature. It was also found that the number of cold nights has been decreasing at a rate of 0.14 day per year.

A low band pass wavelet filter (1.5-16 years) also confirms the upward trend in air temperature. The minimum temperature trend is three times that of the maximum temperature trend (fig 2.2.3 and 2.2.4).

The recent urbanization following the extensive coral fill land reclamation along the eastern coast may have influenced the air temperature observations made at the Seychelles International Airport. Any building and landscape changes would soak up and store daytime solar radiation, in view of the high heat capacity of coral reclamation, bitumen roads and high-rise buildings. This heat is slowly released during the night as long wave terrestrial radiation which keeps the minimum temperature higher than before the development or that in the surrounding open countryside. This effect is known as the 'urban heat island' effect but are localized and have negligible influence (less than 0.006°C per decade over land and zero over the ocean) on global climate (FAR, 2007). There is a lack of air temperature data observations at higher elevations and on the western side of the island to compare the trend in minimum temperature. Therefore, it is rather clear that night temperatures are becoming warmer and less comfortable at certain locations on Mahe.

The National Center of Environmental Prediction (NCEP) assimilated longer (1948-2006) air temperature time series at 2-degree grid size resolution have fairly similar trends and a strong correlation of $r = +0.8$ with the Airport air temperature of the last 30 years. The interesting feature is the warming phase, particularly after mid 1960s, which also corresponds to the 'short term' positive trend in the observed rainfall ($r = +0.6$).

The 2007 monthly average maximum temperature observations show record warming of $+1.7$, $+2.5$ and $+1.3^{\circ}\text{C}$ for January, February and March respectively compared to the 1972-1990 period. The record warming in temperature is attributed to a number of factors such as the development of a moderate El Nino towards late 2006, an active cyclone season to the northeast of Madagascar, a pronounced positive phase of the Madden Julian Oscillation (MJO) suppressing cloud development in the southwest Indian ocean and the potential gradual increase in the background green house global warming effect.

Overall, the latest temperature trends based on maximum and minimum temperature range from $+0.33$ to $+0.82^{\circ}\text{C}$ and are significantly warmer than the previously assessed with $+0.25^{\circ}\text{C}$. The minimum temperature is warming faster than maximum temperature as a result of the 'urban island heat' effect, and the warming is higher during the southeast monsoon. A warming in air temperature is also reflected in the longer-term data sets.

The Fourth Assessment Report (FAR) indicated that eleven of the last twelve years (1995-2006) rank among the 12th warmest years on instrumental record of global surface temperatures since 1850. The updated 100-year linear trend (1906-2005) of 0.74°C (0.56 - 0.92°C) is therefore larger than the corresponding trend of 0.6°C (0.4 - 0.8°C) given in the Third Assessment Report. The linear trend in the last 50 years is twice that for the last 100 years

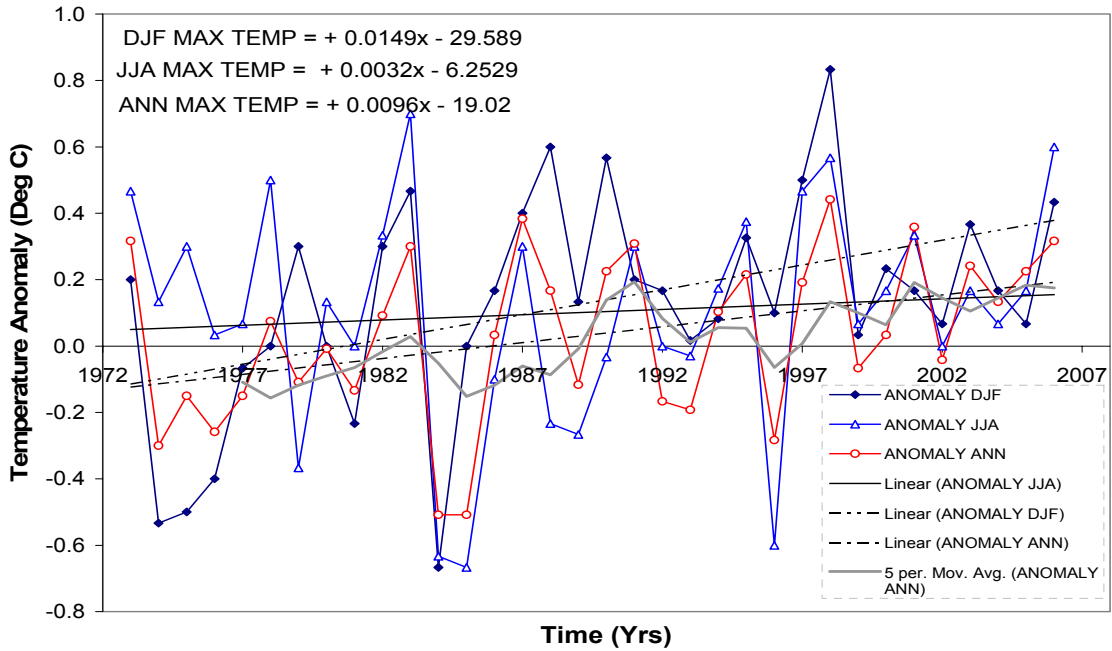


Fig 2.2.1: Seychelles International Airport DJF, JJA and annual maximum temperature anomalies with respect to the 1972-90 period with linear and 5-point moving average trends.

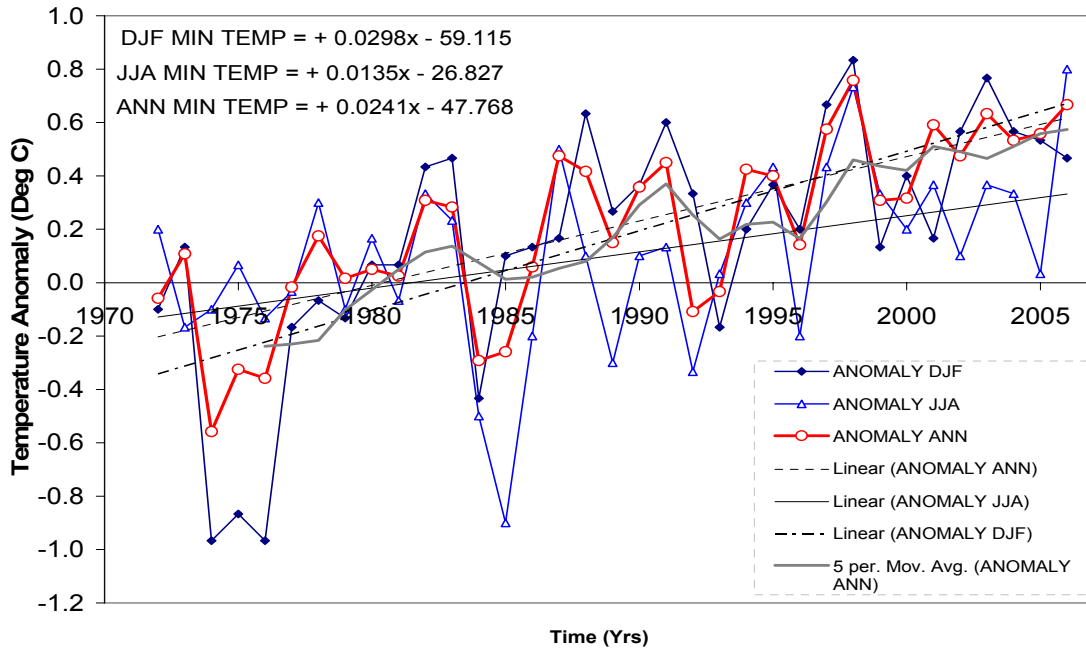


Fig 2.2.2: Seychelles International Airport DJF, JJA and annual minimum temperature anomalies time series with reference to the 1972- 90 period with linear and 5 point moving average trends.

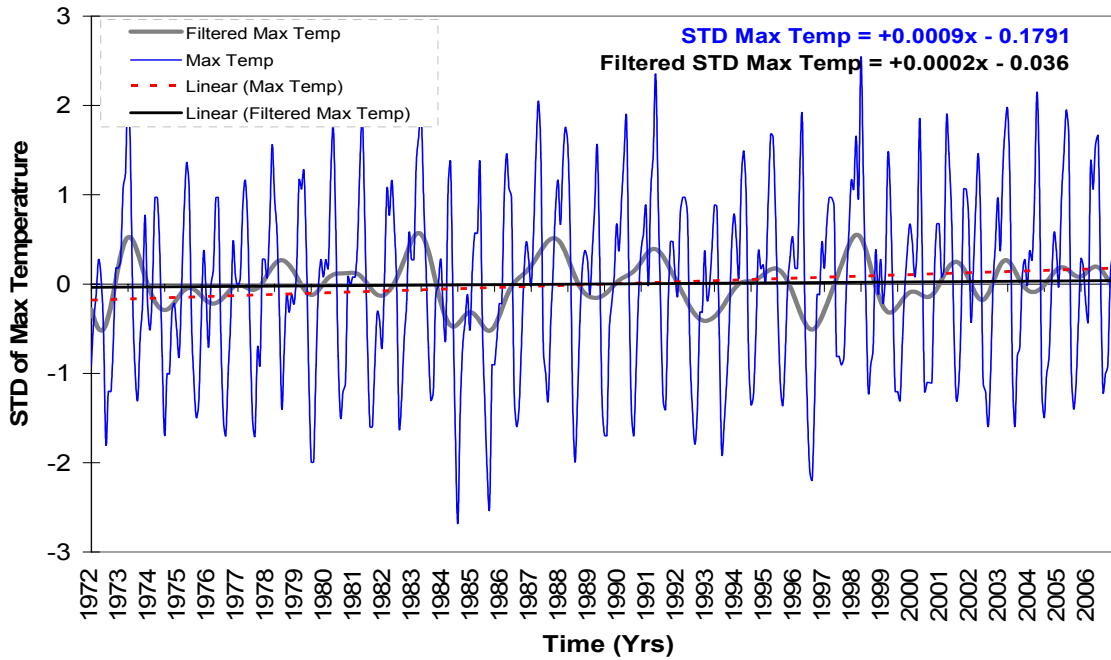


Fig 2.2.3: Standard deviation of monthly maximum temperature and its low band pass wavelet filter (1.5-16 yrs)

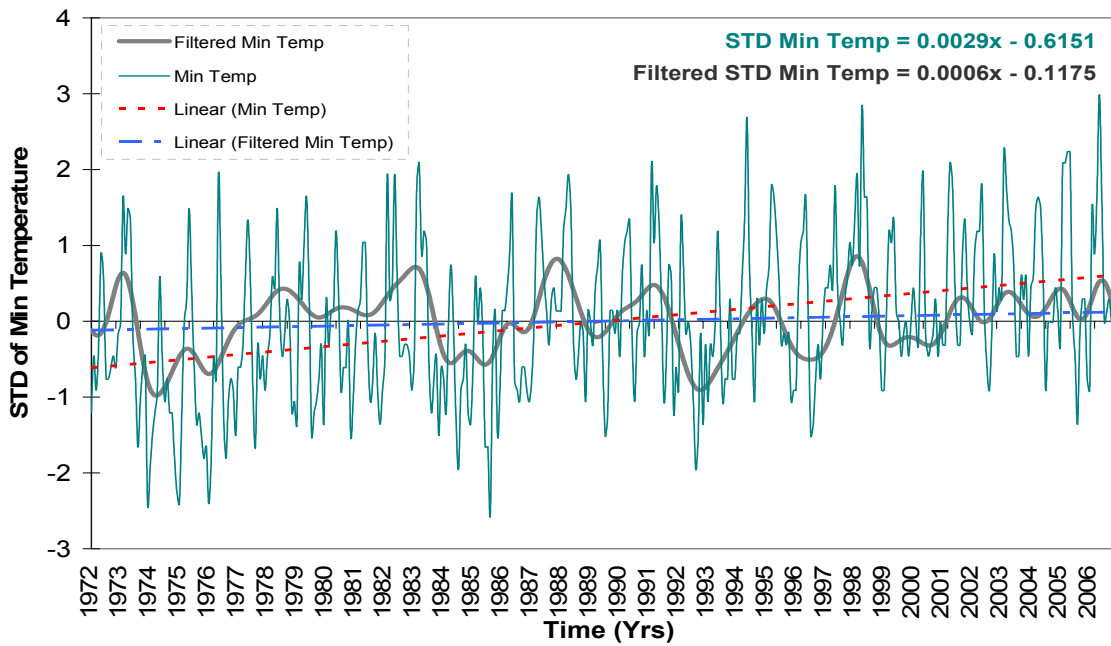


Fig 2.2.4: Standard deviation of monthly minimum temperature and its low band pass wavelet filter (1.5-16 yrs)

2.3 Changes in Sea Surface Temperature (SST)

2.3.1 Temporal and Spatial Changes in SST

The INC highlighted that the SST in the Indian Ocean has warmed only recently and it was assumed that climate variability must have been substantial in the Seychelles. It is not clear which area the SST time series index represented in the Indian Ocean. Nevertheless, ocean atmospheric interactions are much more complex and may not necessarily be only a direct response in the variability of SST in the Indian Ocean. As an example, rainfall and tropical cyclone variability and predictability are dependent on parameters such as SST from other ocean basins such as the Atlantic and Pacific Oceans.

The sea surface temperature observations at Seychelles International, Pointe Larue, show that SST is characterized by two maxima and minima linked to the transition period associated with the reversal of the monsoon winds and the equatorial ocean currents (fig 2.3.1). It is interesting to find that the secondary maxima occur in November and then drop to secondary minima in December before peaking to another maximum in April. The extreme minimum occurs in August at a time when the southeast monsoon is at its peak with the sun in the northern hemisphere. The extreme minimum temperature dropped from 25.8°C in August 2000 to 24.9°C in August 2005. In contrast, the extreme maximum of SST in April 2000 has warmed up to a maximum of 30.1°C in April 2001 following the 1999-2000 La Nina event. Overall, the linear trend suggests a cooling in SST; however no firm conclusions can be drawn from such limited data set. Consequently, the Climate Research Unit (CRU) area monthly time series of SST data at a 2-degree grid size resolution around Mahe Island, Seychelles is analyzed (fig 2.3.2). The 5 and 10-years filtered data are also shown in the same graph. There is a consistent upward trend showing warming in SST after the 1960s. The result agrees well with earlier analysis of the Initial National Communication. The spatial regional scale variability of NOAA SST (1948-2006) relative to the 1960-1990 period shows cooling in the western Indian Ocean, while warming in the east-southeast with a peak of +0.04°C centered between 5-12° S / 55-67°E (fig 2.3.3). The warming in the SST is closely related to

the mean position of the ocean thermocline and the ITCZ in the Indian Ocean. The warm pool in SST in the east-southeastern Indian Ocean was found to be closely linked to the ocean Rossby wave propagation and the inter-annual variability of tropical cyclone and fish resource in the southwest Indian Ocean (Chang-Seng, 2005) at inter-annual time scales. However, more detailed study is recommended to understand the warm pool pattern.

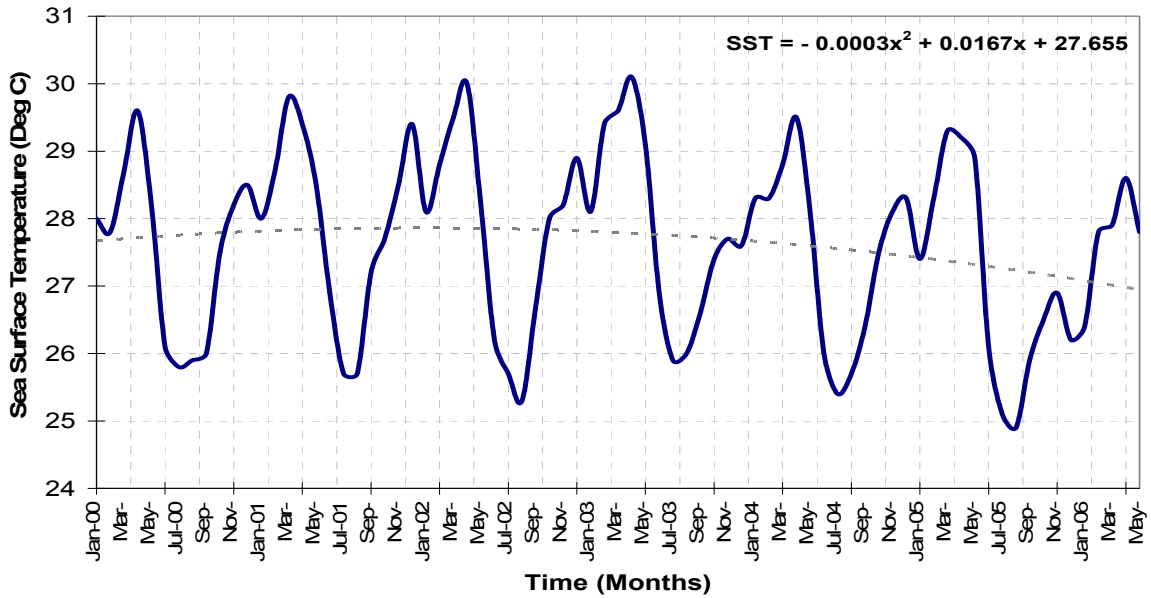


Fig 2.3.1: Sea surface temperature at Seychelles International Airport Point Larue

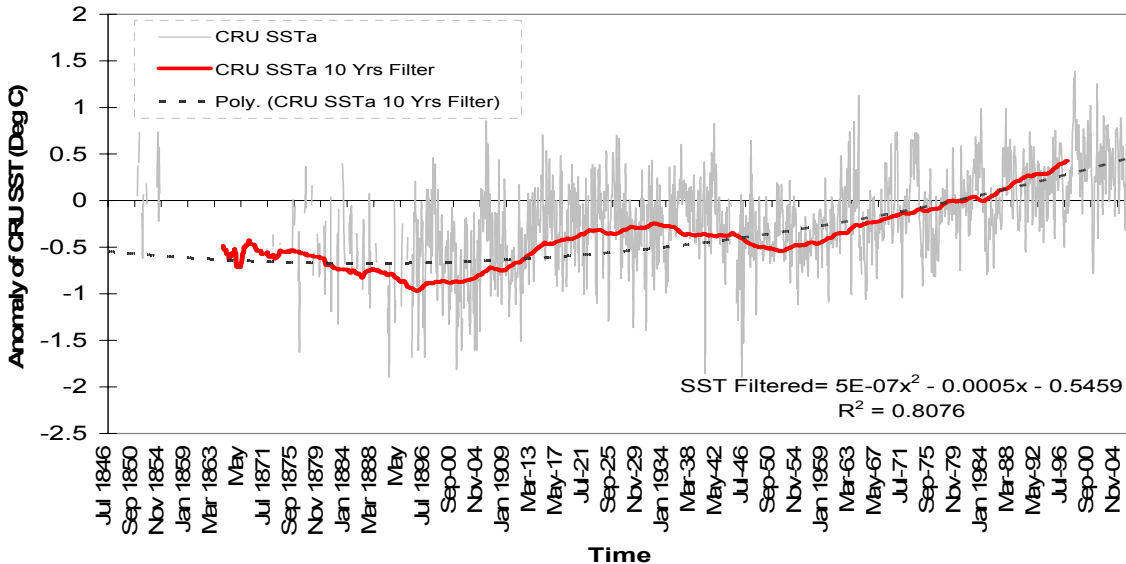


Fig 2.3.2: Area time series CRU SST in the Seychelles. The smoothed curve is the 10-year filter with a quadratic trend

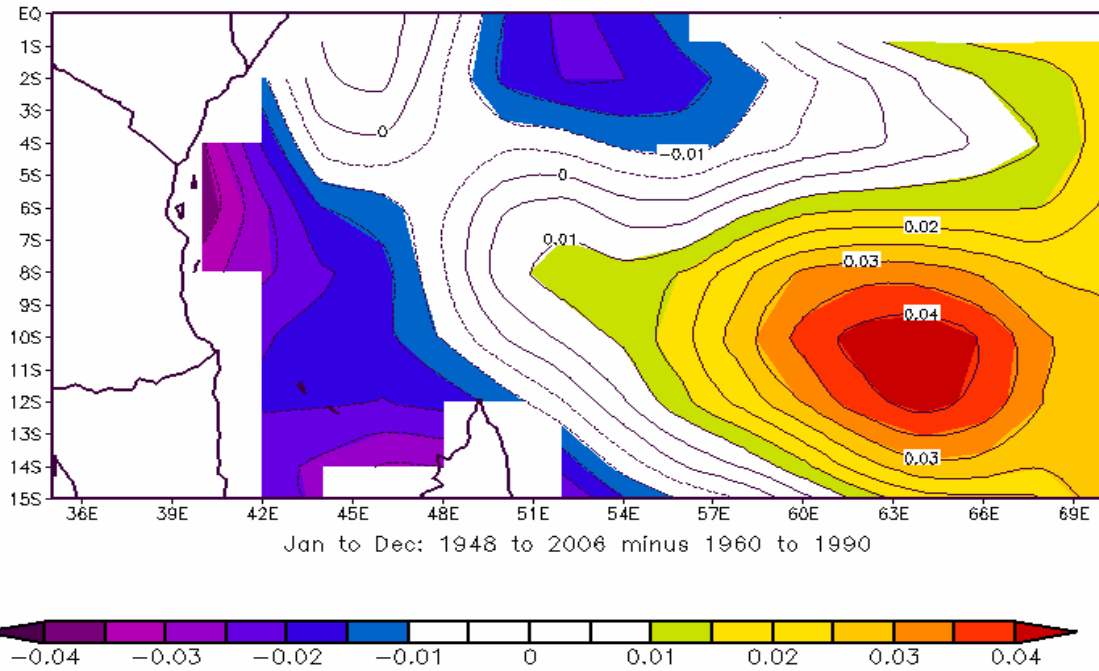


Fig 2.3.3: Spatial change in SST from 1948-2006 relative to the 1960-1990 periods

2.4 Changes in Rainfall

2.4.1 Temporal Changes in Rainfall

Temporal rainfall changes are analyzed for DJF, JJA and the annual time series with respect to the 1972-2006 period at the Seychelles International Airport, Seychelles (fig 2.4.1(a), (b) and (c)). The linear seasonal and annual anomaly trends are +0.6423, + 2.0286 and +13.774 mm per year for DJF (fig 2.4.1(a)), JJA (fig 2.4.1(b)) and annual time series (fig 2.4.1 (c)) respectively. The JJA upward trend is larger than the DJF trend. There are 14 cases in which rainfall has exceeded +50mm in the DJF season, while only 9 cases in which rainfall was at a deficit of -50mm. There are 9 cases for which the rainfall anomalies have exceeded the +50 mm anomaly for the DJF season. It is found that there is only one instance in the year 2000 when rainfall plummeted to a deficit of -50 mm during the strong 1999-2000 La Nina event.

Overall, the JJA dry season has larger upward trend (3 times that of the rainy season) and it is now characterized by wetter-like conditions compared to the 1972-90 period. The low band pass filter of rainfall reveals a surprising downward trend in rainfall (fig 2.4.2).

Extreme precipitation and flooding is now of great concern. However, few studies are available mainly because of an absence of a network of rainfall intensity observation instruments. The existing manual voluntary network of rain gauge only measures 24 hours rainfall. Nevertheless, one measure of extreme precipitation is the percentage of total precipitation due to events above the 95th percentile (R95p). Figure 2.4.2 shows the annual total precipitation when rainfall is greater than the 95th percentile or simply rainfall accounted for by extreme events. As indicated, a strong positive trend is evident (significant at the 5% level). This signifies that heavy rainfall events have been the major contributor to the increase in rainfall (Lajoie, 2004). However, further observations and rainfall intensity analysis are recommended to draw firm conclusions. The Fourth Assessment Report claims that the increases in the frequency of heavy precipitation events are consistent with warming and observed increases of atmospheric water vapour.

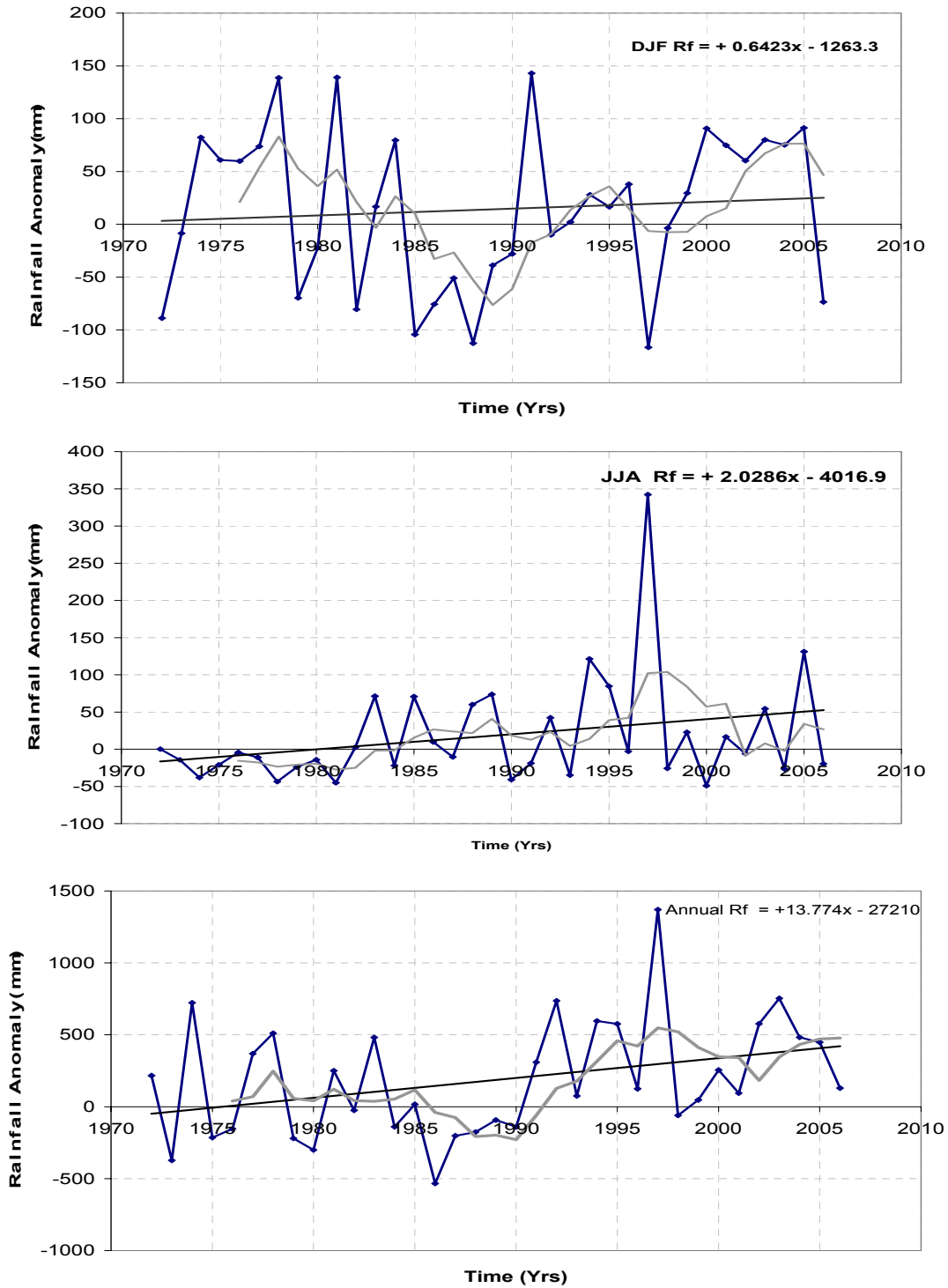


Fig 2.4.1: Time series anomaly of (a) DJF, (b) JJA and (c) annual rainfall at the Seychelles International Airport

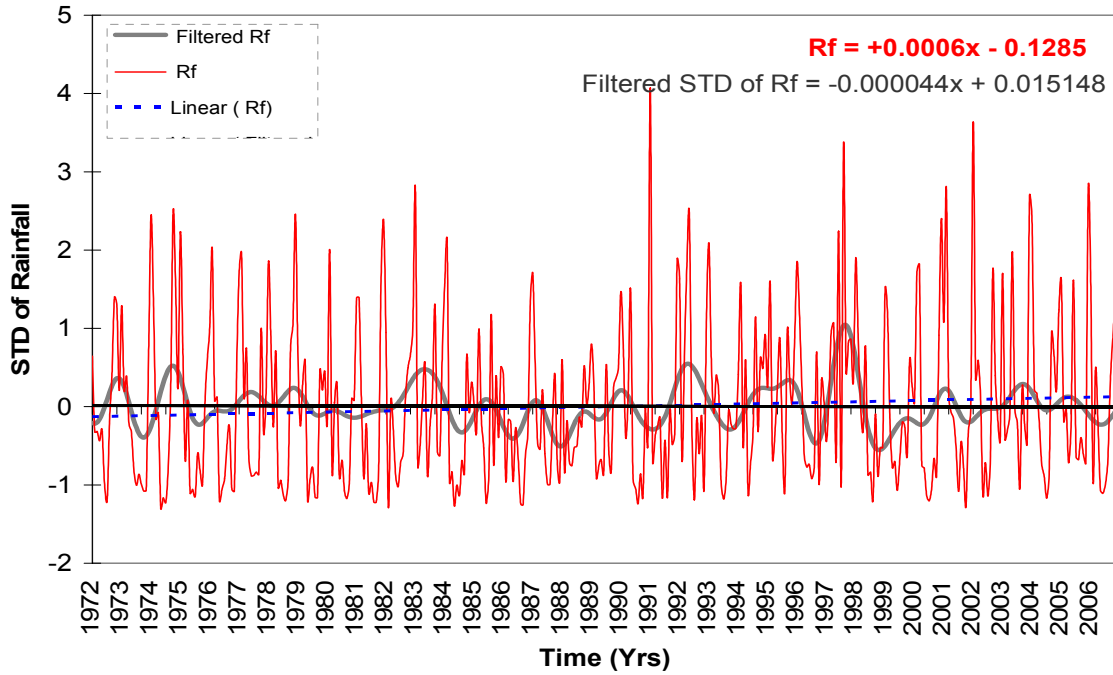


Fig 2.4.2: Standard deviation of monthly rainfall at Seychelles International Airport and its low band pass wavelet filter (1.5-16 yrs)

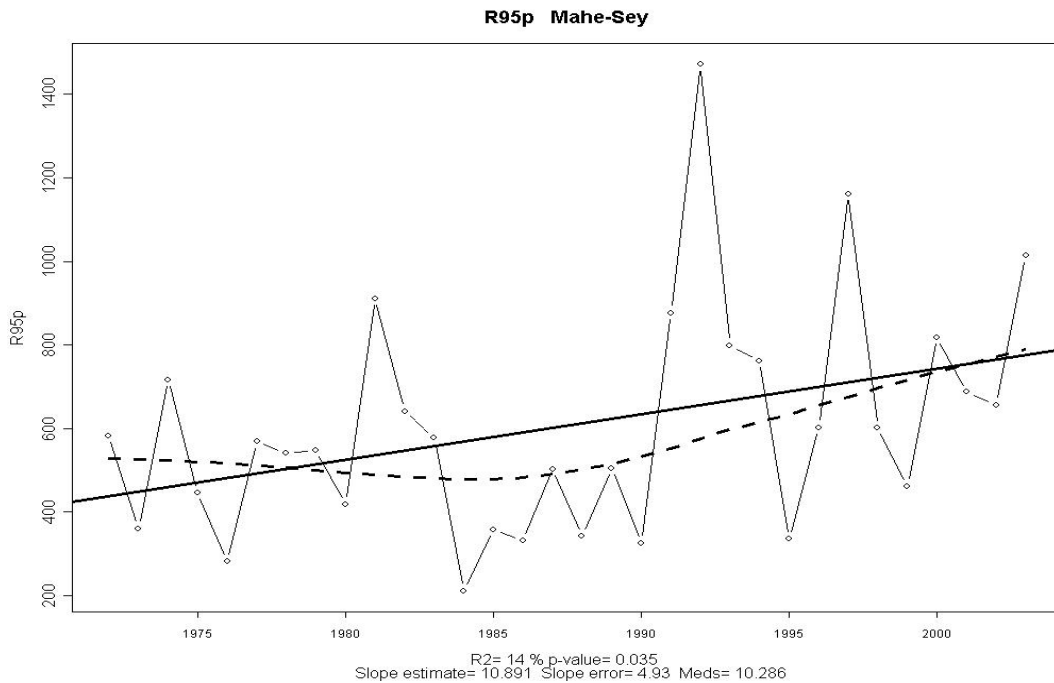


Fig 2.4.3: Annual Total Precipitation (mm) when RR>95p or precipitation accounted for by heavy rainfall events (Source: Lajoie, 2004)

2.4.2 Spatial Changes in Rainfall

The spatial rainfall variability with reference with the 1972-90 periods is assessed. It is found that there is a general increase in spatial rainfall for both the wet (fig 2.4.4 a) and the dry seasons (fig 2.4.4 b). Only Belombre and Anse Boileau areas have a slight decrease in rainfall for the DJF season.

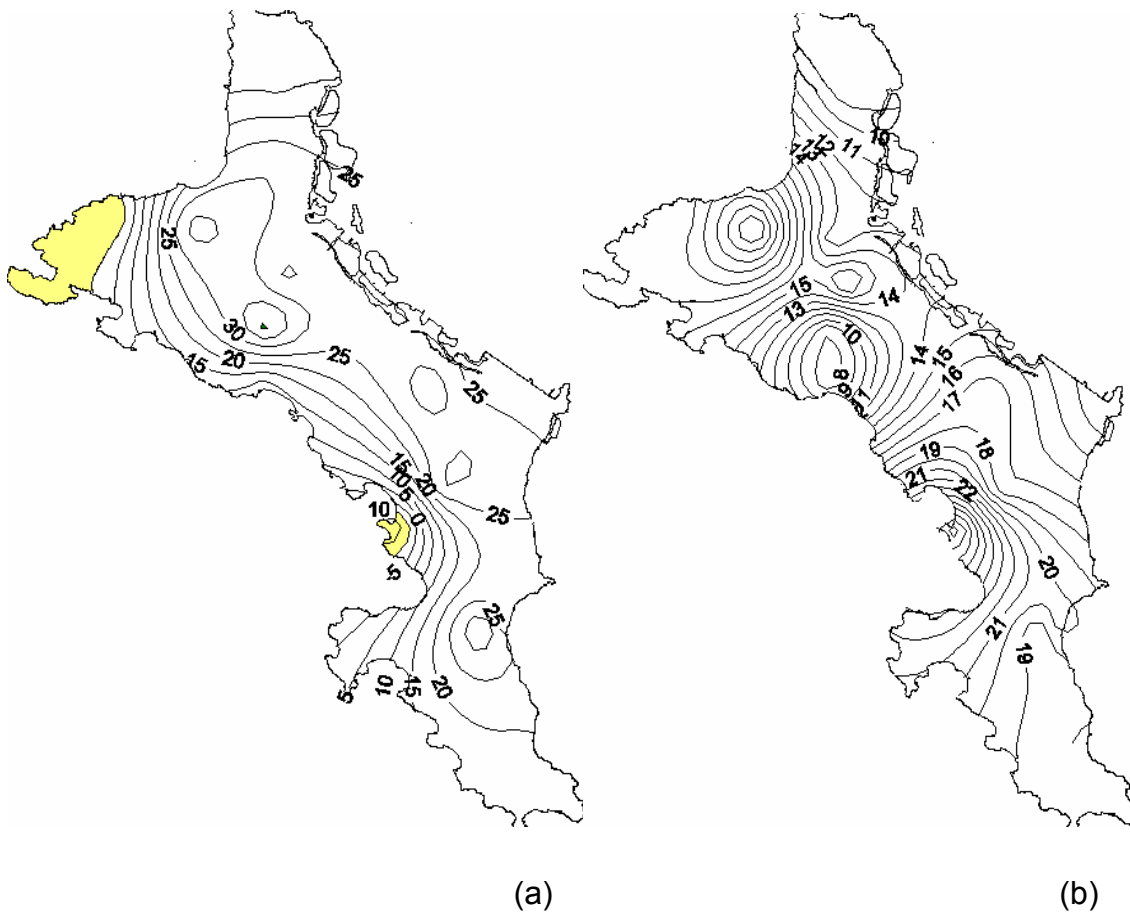


Fig 2.4.4: Mahe spatial rainfall variability for (a) DJF and (b) JJA seasons relative to the 1972-1990 periods

2.4.3 Longer Temporal Changes in Rainfall

The INC briefly assessed past climate changes based mainly on rainfall records dated back to 1890s published by Stoddard et al., (1979). However, little is known about the origin, quality and availability of the data. In this section, the longer rainfall trends are analyzed using a merged observed rainfall data set.

A rainfall time series was constructed by merging rainfall observed at the Botanical Gardens, Mont Fleuri (1897 to 1961), Port Victoria (1921-1971) and the Seychelles International Airport (1972 to 2006). The three rainfall observation stations are less than 10 km apart and are fairly equally affected by local orographic-type of rainfall. It is well known that all the rainfall stations are highly correlated. The stations fall in the same rainfall zone according to the principle component analyses (PCA). The Student T-test and analysis of variance (ANOVA) were carried out for paired and grouped station rainfall to examine the statistical significance of the individual data sets. It is found that the t-values range from 0.104 to 0.39 with a corresponding probability of a null hypothesis ranging from 0.7(70%) to 0.97(97%). ANOVA puts all the data into one number (F) and gives *one P* for the null hypothesis. The P-value is found to be 0.98. Since the P-values are greater than ($P > 0.7$), it is assumed that the data sets are *not statistically significantly different*. In addition, the data sets are examined for outliers. Therefore, the three stations rainfall data were merged to create a single data set without modifying the original data.

The merged data set confirms that Mahe rainfall is fairly highly variability as indicated in the monthly time series (fig 2.4.5). The peak rainfall occurred in January 1955 with a total of 942mm. The rainfall anomaly is +748mm while the minimum rainfall was observed in October 1910 with only 1 mm representing a deficit of -192 mm. The smooth curves superimposed on the monthly rainfall time series are the 5 and 10-year filtered monthly rainfall data. Figs 2.4.6 is a close up visualization of the same rainfall smoothed curves. High anomalous rainfalls are observed between the periods 1925-1940s, 1950-1970s and 1990-2000 with rather low anomalous rainfall in the remaining years. It is found that the rainfall time series has a positive trend showing rainfall increasing at +2mm per year (not shown). However, no significant

climate trend is observed in the case of the smoothed 5 and 10 year trend. On the other hand, there are unique and distinct rainfall cycles of 2-4, 10 and 30-year cycles (fig 2.4.6 to 2.4.7). The 2-4 year cycles have strong spectral energy (occurrences) during the periods 1910 -1930, 1948-1968 and 1988-2000 apparently corresponding to the occurrences of the known ENSO years. In addition, the strong biennial (~2 year) cycle is much related to the QBO (Quazi Biennial Oscillation) and appears to be unrelated to the TBO (Tropospheric Biennial Oscillation) which is associated with variations in the tropical atmospheric circulation and sea surface temperature (SST) over the tropical Indian Ocean.

The decadal cycles were particularly strong from 1900 to the 1970s. The decadal rainfall cycle has previously been suggested to be linked to the sunspot cycle (Marguerite, 2001) and the decadal variability in intense tropical cyclone (Chang-Seng, 2005). The most interesting climate related cycle is the 30-year cycle characterized by periods of abnormally high and low rainfall trends operating as a background low climate signal. The 30-year cycle was most active, as indicated, by the moderate wavelet spectral energy from 1900 to the 1970s. It is suggested that the 30-year natural cycle is "tele-connected" to the Atlantic Multi-Decadal Oscillation (AMO) in sea surface temperature ($r=+0.25$). The physical mechanism may be related through the processes of the deep ocean thermohaline circulation which distributes heat globally. However, further studies are recommended to draw better conclusions. It is noted that the degrees of freedom is 59, thus 95% significance is achieved with a correlation of more than 0.2. The 30-year cycle has gradual, but significant influence on the long term climate variability of the Seychelles. There is no clear evidence to suggest any consistent upward trend in rainfall caused by natural or non-natural forcing.

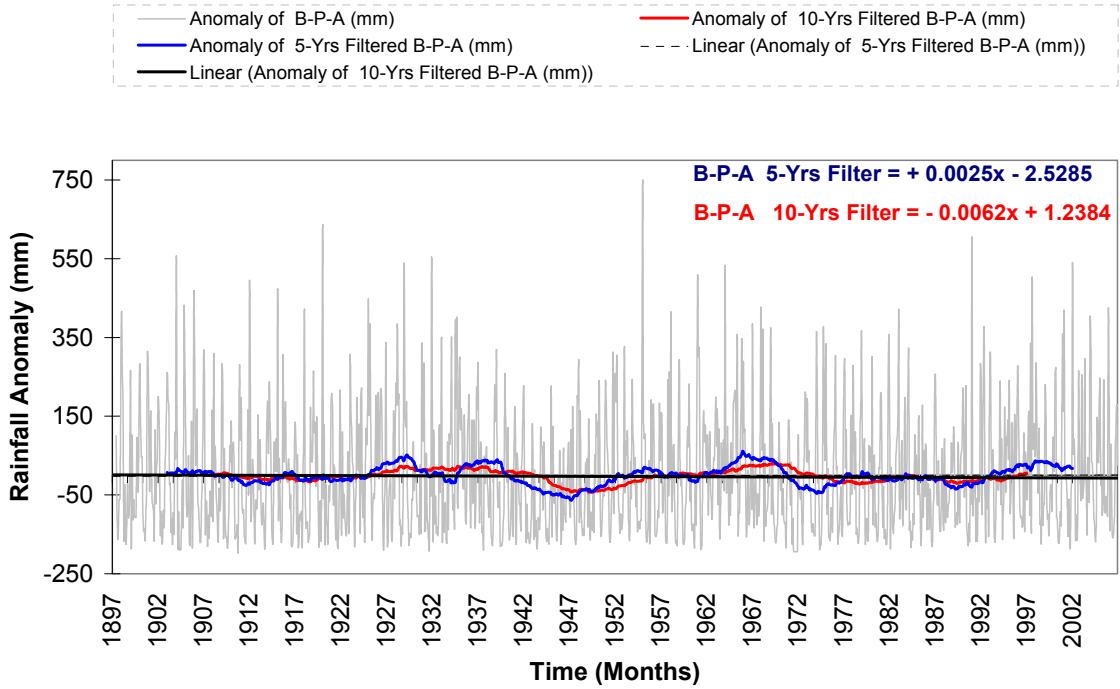


Fig 2.4.5: Time series of raw merged rainfall anomaly for the Botanical Gardens, Port Victoria and Seychelles International Airport rainfall anomaly and 5 and 10 years filter

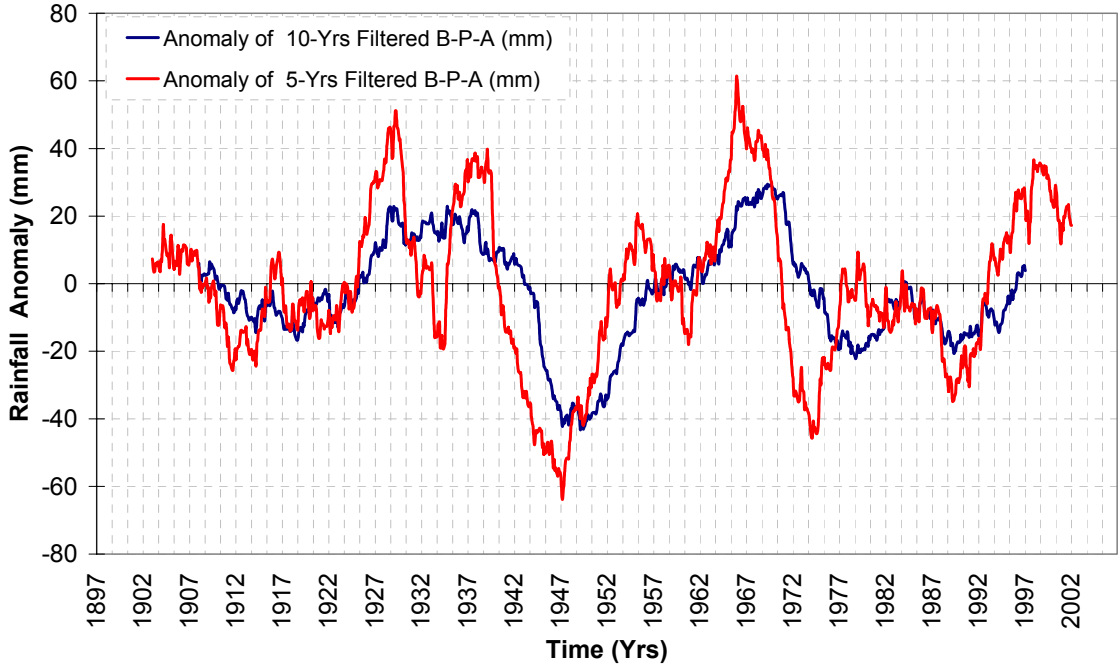


Fig 2.4.6: Filtered (5-Yrs and 10-yr) of raw merged rainfall data at the Botanical Gardens, Port Victoria and the Airport.

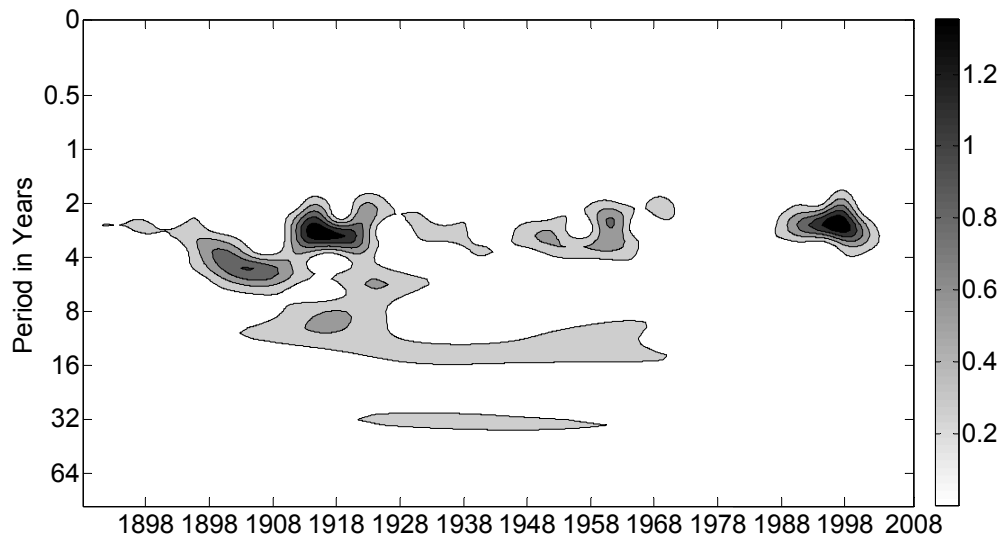


Fig 2.4.7: Wavelet power spectral analysis (low pass filter >1.5 yrs) of raw merged rainfall data at the Botanical Gardens, Port Victoria and the Seychelles International Airport

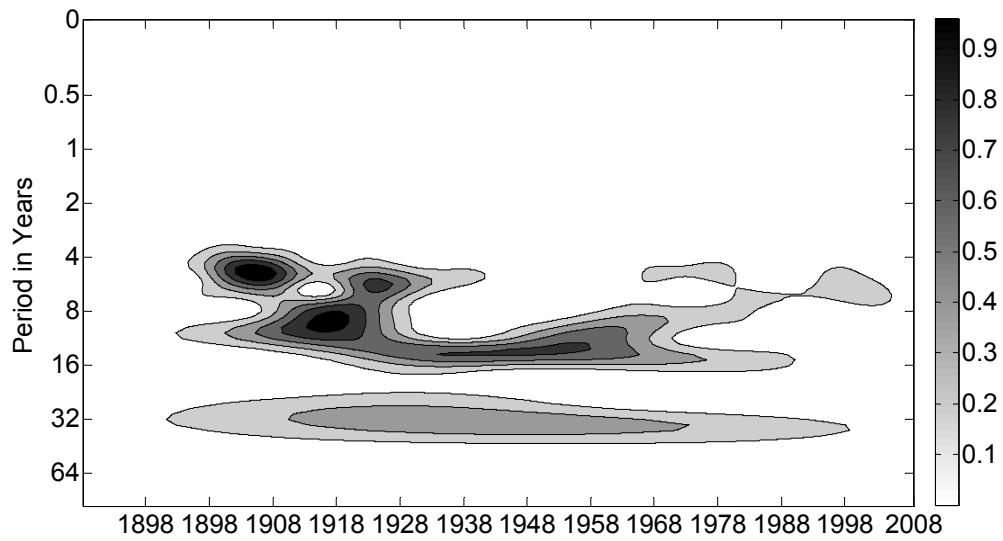


Fig 2.4.8: Wavelet power spectral analysis (low pass filter >3Yrs) of raw merged rainfall data at the Botanical Gardens, Port Victoria and the Seychelles International Airport

2.5 Changes in Sea Level

2.5.1 Temporal Changes in Sea Level

The underlying cause of sea level rise is due to the decline of mountain glaciers and snow cover in both hemispheres. In addition, the average temperature of the global oceans has increased to depths of at least 3000m and the ocean is absorbing more than 80% of the heat added to the climate system since 1961. Such warming causes sea water to expand, contributing to sea level rise (FAR, 2007).

There are several quality Global Sea Level Observing System (GLOSS) monitoring stations in the southwest Indian Ocean (SWIO). Table 2.5.1 shows the details of the SWIO Permanent Station for Monitoring Sea Level (PSMSL) GLOSS station. Currently, only the Pointe Larue Station which was installed in 1993 is monitoring quality sea level in the Seychelles waters (fig 2.5.1).

Recently, there has been a notable increase in the gradient of the mean sea level slope as highlighted by an arrow on the sea level time series (fig 2.5.1). From 2002 to 2006, there are 5 instances when sea level anomaly has exceeded +10 cm. Consequently, although not properly documented, there have been increased reports of coastal impacts. Figure 2.5.2 shows the annual sea level trend anomaly of +0.146 cm per year which is in close agreement with the trend computed by the PMEL in August 2005. It is important to note that the standard error in the case of the Pointe Larue Station is ± 2.11 mm per year. There is still a positive trend even after the high frequency signals are filtered out (fig 2.5.3).

2.5.2 Spatial Changes in Sea Level

Figure 2.5.4 shows the current sea level trends and its standard error in the southwest Indian Ocean. Apart from three stations, most stations are reporting a small positive trend particularly in the Mauritius and Reunion area; however the standard error is also quite large (fig 2.5.5). The results are consistent with the latest publication of Ragoonaden(2006) which concluded that most stations were reporting some rising trend while others had a negative trend. Figure 2.5.6 shows the negative

sea level in the southwest Indian Ocean derived from the satellite altimetry of the TOPEX/Poseidon observation from 1993-2003 (Leuliette et al.,2004). Ragoonaden also concluded that there were no clear indications of enhanced or abnormal acceleration in the sea level rise. The local sea level trends are rather consistent with the global average sea level rise of an average rate of +1.8 mm (1.3 to 2.3 mm) per year over the 1961 to 2003 periods. It is highlighted that the rate was faster over the 1993 to 2003 periods, about +3.1 mm (2.4 to 3.8 mm) per year. It is not clear if the faster rate is linked to decadal variability or to an increase in the longer-term trend.

The sea level variability in the last few years have also been influenced by extreme equatorial and mid-latitude generated storm surges and swells, as was the case with cyclone "Bondo" in December 2006 and the latest 'high wave" event which unfolded between 13th-20th May 2007.

Coastal erosion and inundation are often viewed as a result of sea level rise, but in reality although not conclusive, coastal development has frequently caused coastal current and dynamics to alter only to cause negative impacts on the environment. Proper coastal modeling, engineering and assessment should help in minimizing the impacts of any development.

Country	Start	End	Trend (mm/yr)	Standard Error (mm/yr)	Lat	Long				
MAPUTO	1961	2000	1.24	0.51	25	58	S	32	34	E
MOCAMBIQUE ISLAND	1963	1966	14.36	7.05	15	2	S	40	44	E
NOSY-BE	1959	1972	-3.54	2.84	13	24	S	48	17	E
PT. LA RUE	1994	2003	1.05	2.11	4	40	S	55	32	E
PORT LOUIS	1942	1965	2.98	0.94	20	9	S	57	30	E
PORT LOUIS II	1987	2003	-0.94	1.9	20	9	S	57	30	E
RODRIGUES IS	1991	2003	3.95	2.5	19	40	S	63	25	E
POINTE DES GALETS	1979	1985	-1.58	4.59	20	56	S	55	18	E
DIEGO GARCIA-C	1989	2000	2.26	3.63	7	17	S	72	24	E
GAN II	1992	2003	5.76	1.71	0	41	S	73	9	E
MALE-B, HULULE	1993	2003	2.03	1.36	4	11	N	73	32	E
ZANZIBAR	1985	2003	-3.75	1.11	6	9	S	39	11	E
MOMBASA	1989	1999	3.69	2.85	4	4	S	39	39	E

Table 2.5.1: PSMSL GLOSS station, number of years of data used to compute the trend, range of years used, trend and standard error in mm/year, latitude and longitude and station name. (Source: PMEL, August 2005)

POINT LA RUE 04 40S 055 32E Seychelles 1993-2006

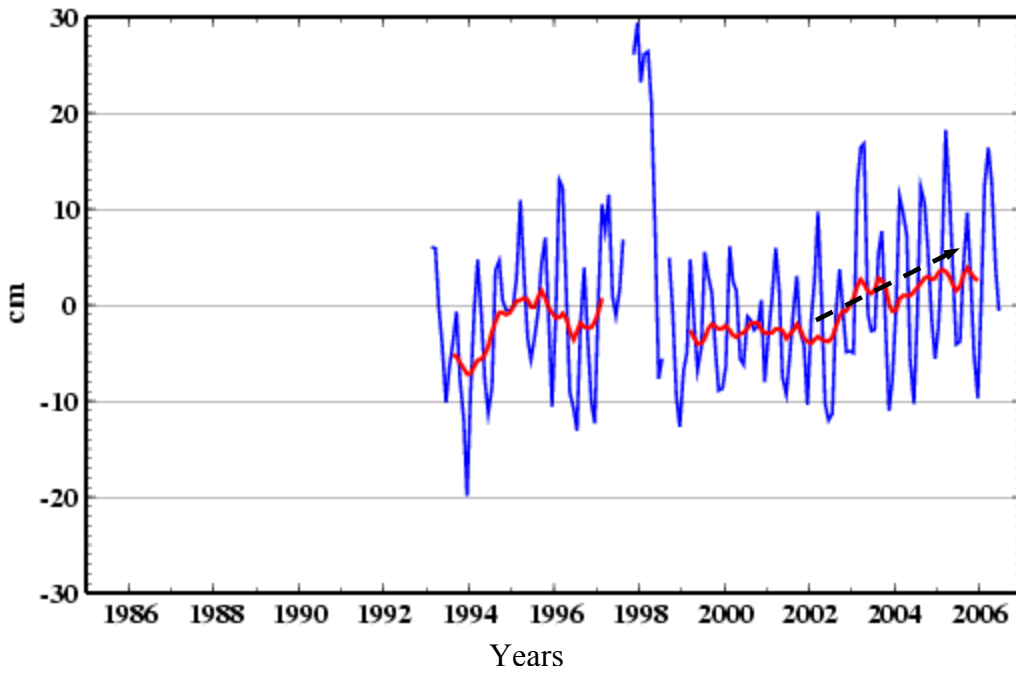


Fig 2.5.1: Time series of Pointe Larue observed monthly sea level anomaly. Red curve is smooth sea level (Source: University of Hawaii)

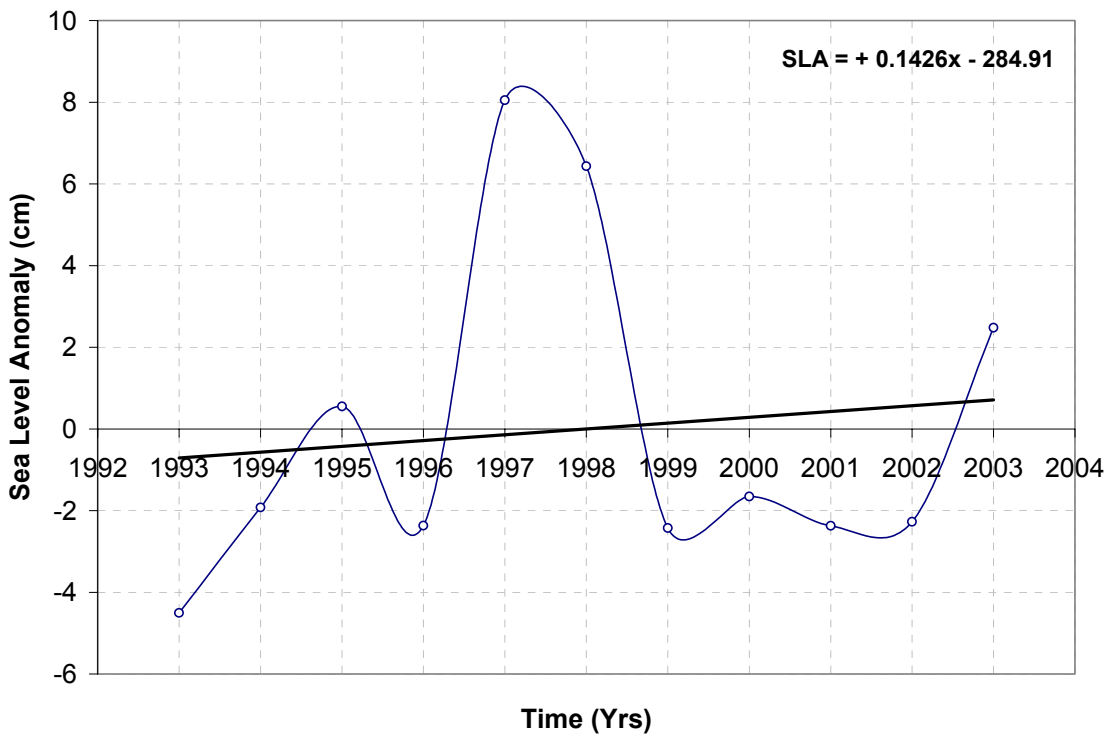


Fig 2.5.2: Time series of Pointe Larue monthly sea level anomaly

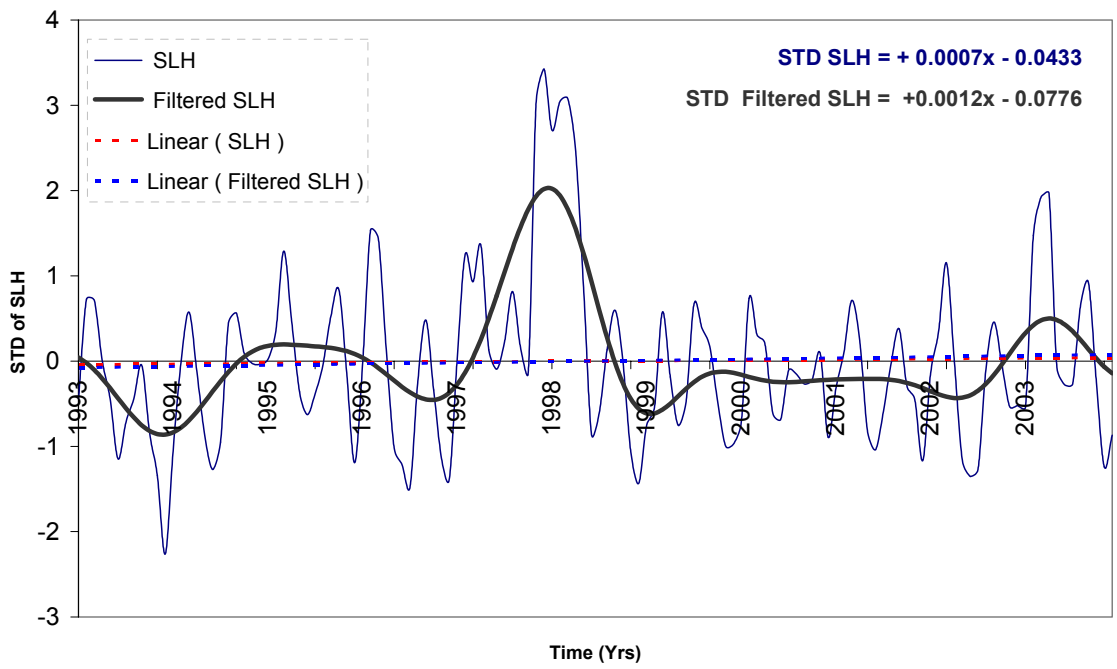


Fig 2.5.3: Standardized monthly sea level at Pointe Larue and its low band pass filter

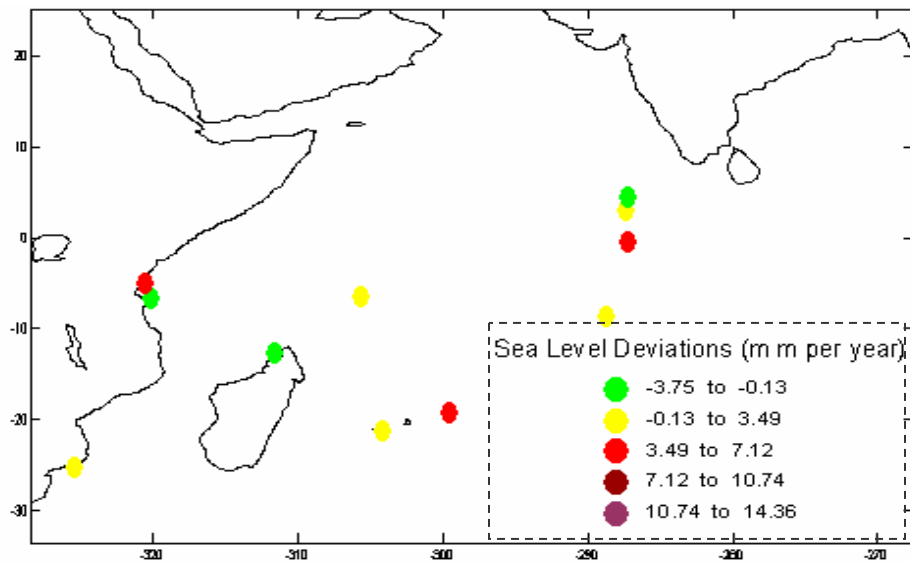


Fig 2.5.4: Sea level trend in mm per year in the southwest Indian Ocean

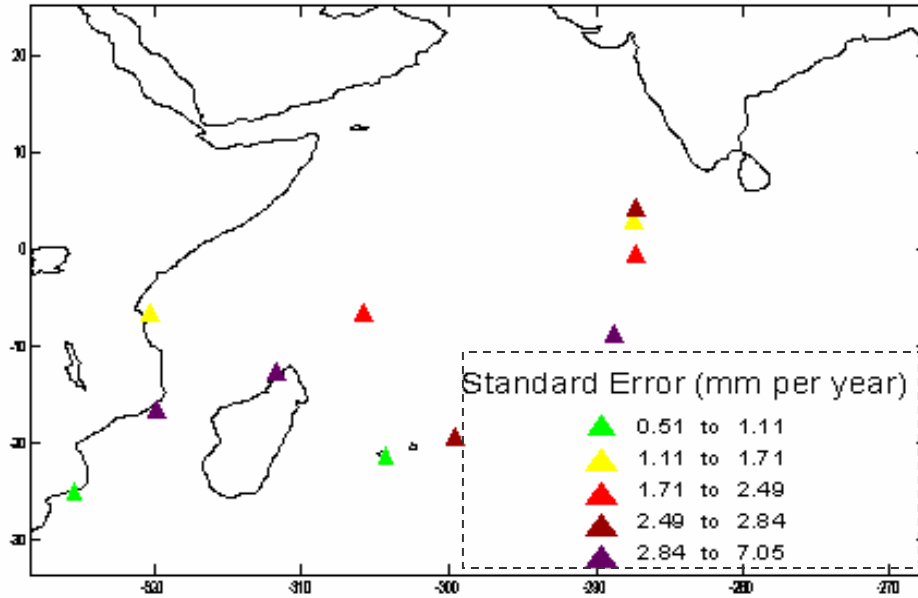


Fig 2.5.5: Standard error in sea level trend in mm per year in the southwest Indian Ocean

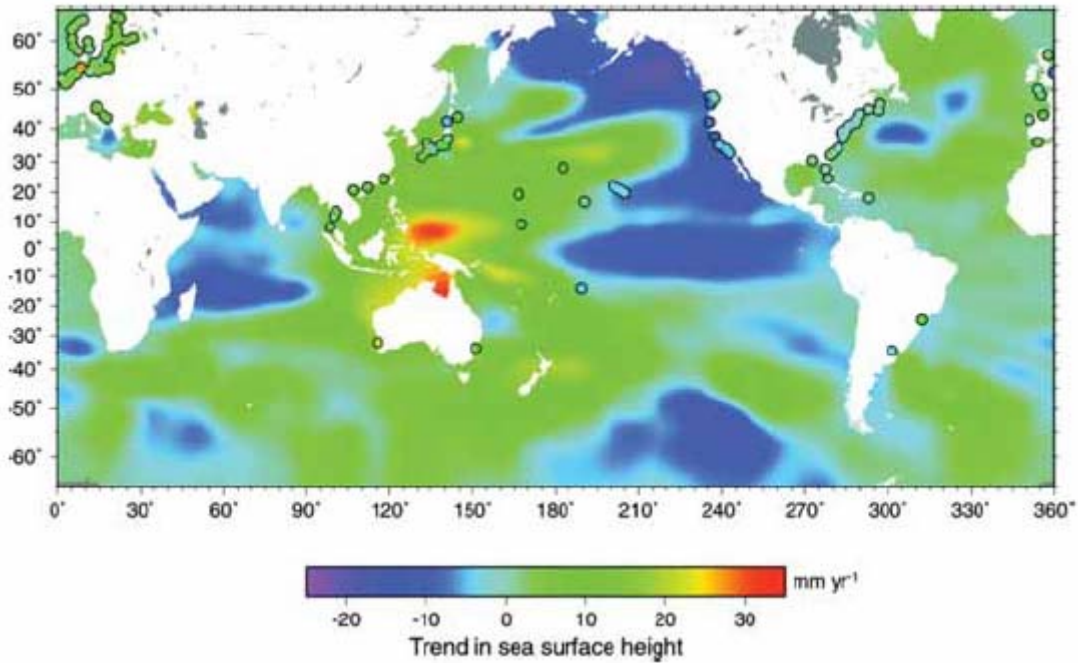


Fig 2.5.6: Altimetry-derived sea level map for TOPEX/Poseidon observation for the 1993-2003 periods (Source: Leuliette et al., 2004)

2.6 Changes in Tropical Cyclone

There was no assessment of tropical cyclone variability and change in the Initial National Communication. However, the islands south of the equator such as Mauritius, Reunion, Madagascar, Agalega and Comoros are directly affected by the impacts of tropical cyclones (TCs). The equatorial regions of the study area which includes the Seychelles are well known to be indirectly affected by tropical cyclones via the intensification of the ITCZ (Walsh, 1993) and spiral rain bands associated with TC passing south of the islands. In a recent study entitled 'Marine weather variability, tropical cyclone prediction and impacts in the southwest Indian Ocean', Chang-Seng (2004) highlighted that the Seychelles have its fair share of cyclonic impacts through intense rain equivalent to rain rates in the inner core of tropical cyclone. The TC generated swells have significant wider basin impact, posing a risk to maritime users within the Seychelles EEZ. In the same study, it was shown that spatial rainfall variability was dependent on TC track. The prime motivation for assessing tropical cyclone trends and risks for the Seychelles is of national importance. This follows from the impact of the tropical depression on Praslin in September 2002 (fig 2.6.1) and the recent historical and direct impact (fig 2.6.2) of intense tropical cyclone 'Bondo' on the 22nd December 2006 on Providence and Farquhar. Fortunately, no lives were lost. Therefore, it has become a national concern if the SWIO is getting stronger and more frequent tropical cyclones. What about climate change? Is the cyclone risks area widening?

2.6.1 Temporal Changes in Tropical Cyclone

The variation in the number of intense tropical cyclones (central pressure below 945 hPa) in the south-west Indian Ocean was studied over the last thirty years by Hoareau (1999). The intensity of cyclones was estimated through the interpretation of satellite pictures. It was found that the number of intense tropical cyclones had a tendency to increase especially in the case of the extreme systems (pressure below 920 hPa) for which a stronger increase in frequency occurred over the period 1990-99. This increase in intense tropical cyclone is not steady: a slight decrease in the number of intense cyclones took place over the decade 1980-89. There was no

increase in intense TC associated with the 1980s ENSO. In contrast, the decade of 1990-99 shows the greatest number of intense cyclones. Figure 2.6.3 shows the variations in the number of intense TCs for different categories according to the Dvorak classification in the SWIO. It indicates an increase in intense TCs in the SWIO with a total of 27 TCs for the decade 1970-79 and 34 for that of 1990-99. Similar trend in intense TCs is observed in the north Atlantic and northeast Pacific cyclone basins.

Chang-Seng (2005) studied TC mechanisms, structure, and variability in the southwest Indian Ocean using an intense tropical cyclone days index from Meteo France Reunion Tropical Cyclone Warning Center and the NCEP 4-D model-assimilated ocean and atmospheric data. An intense tropical cyclone day is defined by the identification of a cyclone with an eye visible on the satellite image and with wind speed of over 180 km per hour. It was found that the decade 1960-69 was the most active with an anomaly of + 4 intense tropical cyclone days, while that of 1980-89 was the least active with an anomaly of -6 intense tropical cyclone days in the SWIO. After the 1990s the anomaly was +2 intense tropical cyclone days. The linear trend is negative with a decreasing rate of 0.14 intense tropical cyclone day per year in the southwest Indian Ocean from 1960 to 2002 (fig 2.6.4: Updated version). Using power spectral analysis it is revealed that the intense TC index is characterized by biennial to decadal cycles (fig 2.6.5) that have been found to be related to the Quasi Biennial Oscillation (QBO- biennial reversal of stratospheric wind) and the deep ocean thermohaline circulation respectively. Currently, the intense TC trends suggest that SWIO is experiencing a suppressing decadal cycle.

In the same study it was found that the dominant factor controlling TC days variability is the geo-potential height zonal wave number 3 pattern, that 'foretells' of reduced wind shear over SWIO through the mechanisms of bifurcation of the jet stream and the enhanced tropical upper easterlies / lower westerlies and cyclonic vorticity over SWIO. A related mechanism is the anti-phase association between the South American monsoon and SWIO TC days through the Atlantic zonal circulation particularly during ENSO years. It was found that the role of the transient coupled Rossby wave on sea surface temperature and its associated westward co-

propagating cyclonic circulation is of importance to intense TC days prediction and fish resources of the region. Thus, an improved multivariate model was developed for the prediction of intense TC days in the SWIO region (48 % of TC days variability explained). Figure 2.6.7 illustrates the conceptual model of TC variability in the SWIO (Chang-Seng, 2005).

Similarly, figure 2.6.6 shows that the tropical cyclone (wind speed between 118 and 165 km per hour) anomaly with respect to the 1967-1990 periods has decreased as indicated by the downward trend rate of -0.023 tropical cyclone day per year. In contrast, the number of tropical depression (wind speed of less than 117 km per hour) has a positive trend +0.025. The area time series index of SST in the warm pool (fig 2.3.3) in the south central Indian Ocean is statistically significant with the tropical depression time series index.

2.6.2 Spatial Changes in Tropical Cyclone

The confronting question which is of great importance and relevance to the Seychelles is whether or not the cyclone risks area is widening as a result of possible potential anthropogenic climate change. It is believed that with a global warming, anomalous warming will probably extend into the lower latitude. Thus conditions would become more favourable for low latitude cyclonic development. Recent events of the landfall impacts of tropical depression on Praslin and intense tropical cyclone 'Bondo's' direct impact on Providence portray that the cyclonic belt and risks area is widening.

It is highlighted that it is *physically not impossible* for cyclonic systems to develop or track equatorwards. The path of each storm varies considerably in response to the weather patterns occurring at the time. Tropical cyclones can be thought of as being steered by the surrounding environmental flow. Short-term fluctuations in the track are common for intense cyclones. TC track changes towards the lower latitude has been established to be driven by the presence of a strong persistent anticyclone in the central SWIO; causing mid-level easterlies in a core region between 10°S and 20°S, 35–65°E (Parker and Jury, 1999; Chang-Seng, 2005).

There have been few or no studies in the southwest Indian Ocean that have investigated tropical cyclone spatial variability. Secondly, though historical tropical cyclone trajectory data is relatively short, it is found that the outer islands have been previously affected by various TCs. However, there has been very few detailed documentation and reports of the impacts. For instance, the 1862 avalanche in Victoria was associated with an unknown TC intensity coded as 'xxxx862068'. It was located at 3.6 S, 59.0 E on the 11th October and at 6.0 S, 54.2 East on the 14th October. On the 18-28 December 1950, a TC coded as 'xxxx950670' was centred less than 190 km south of Farquhar islands. Between the 16 and the 28th October 1973 a severe tropical storm named 'Bernadette' tracked 20 km north of Farquhar island. On 5th-14th December 1983 a full blown tropical cyclone named "Andry" tracked 110 km south of Farquhar. Figure 2.6.8 demonstrates the historical cyclonic risks for the islands of the Seychelles based on data from 1848-2003. However, low latitude cyclonic systems are very rare with a probability of occurrence once every 10 years with a high chance of cyclogenesis during the transition months. They are normally of lower intensity and endure rapid intensity deterioration as a result of low coriolis force.

According to the IPCC Fourth Assessment Report there is observational evidence to suggest an increase in intense cyclone activity in the North Atlantic since the 1970s, correlated with increases in SST. However, there is no firm evidence of changes in cyclone activity and number in other ocean basins due to lack of quality data prior to routine satellite observations. It is also highlighted that multi-decadal cyclone activity as discussed earlier also complicates the detection of long term trends in cyclone activity.

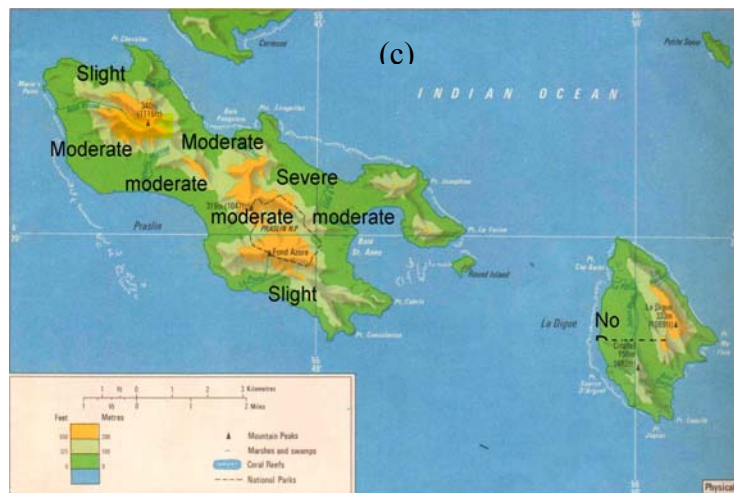
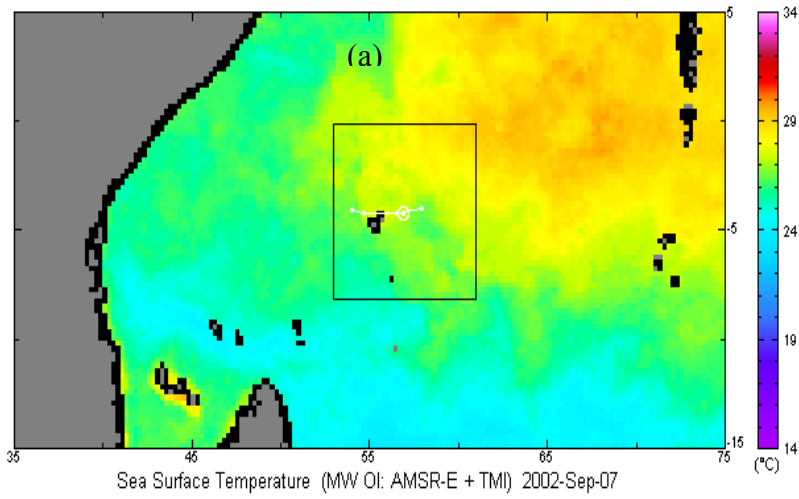


Fig 2.6.1: (a) Tropical depression 01 S track (b) Uprooted trees within the compounds of La Reserve Hotel Praslin and (c) Level of damage assessed on Praslin as a result of the 6-8th September 2002 storm (Source: Seychelles Meteorological Services)

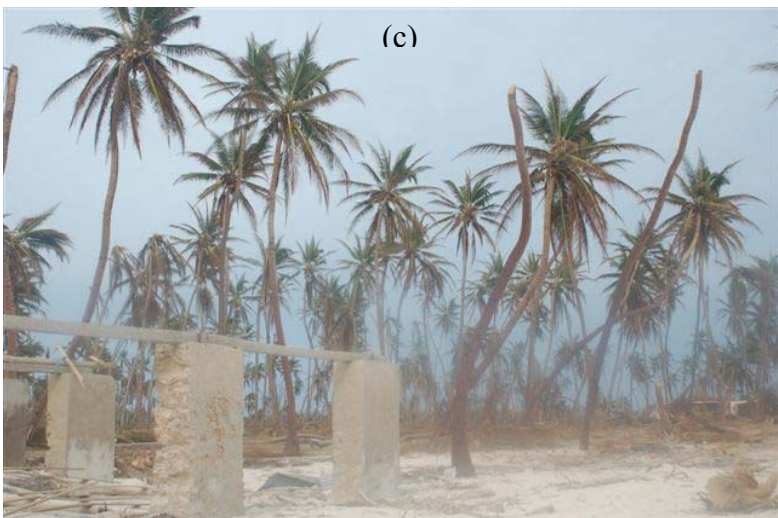
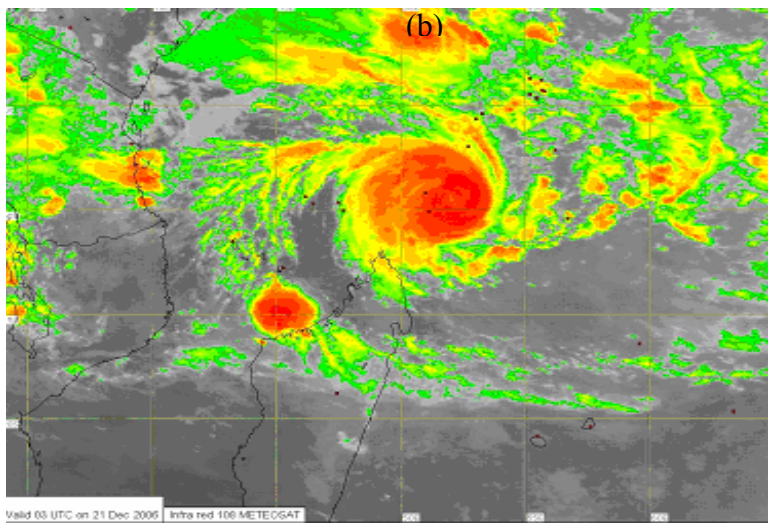
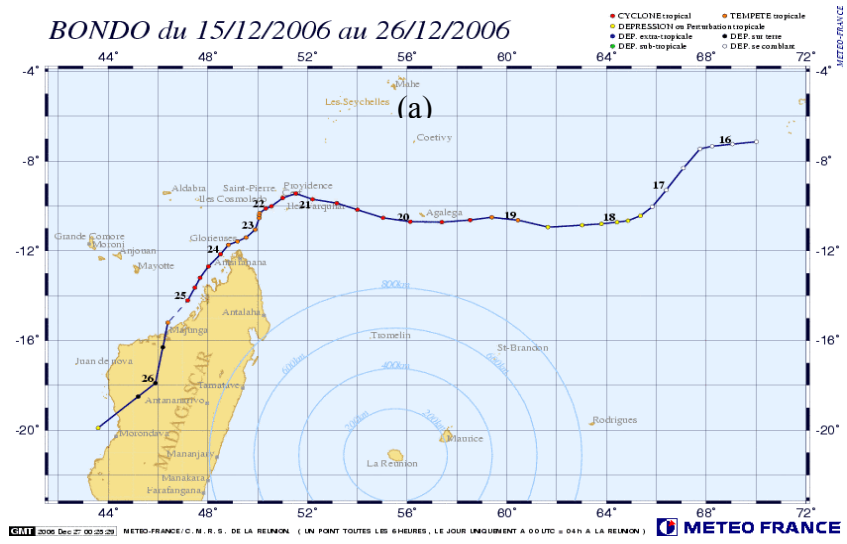


Fig 2. 6. 2: (a) Intense tropical cyclone 'Bondo' track (b) satellite imagery (Meteorological Services, 2006) and (c) impact on Providence island (Source: Adrian Skerret, 2006)

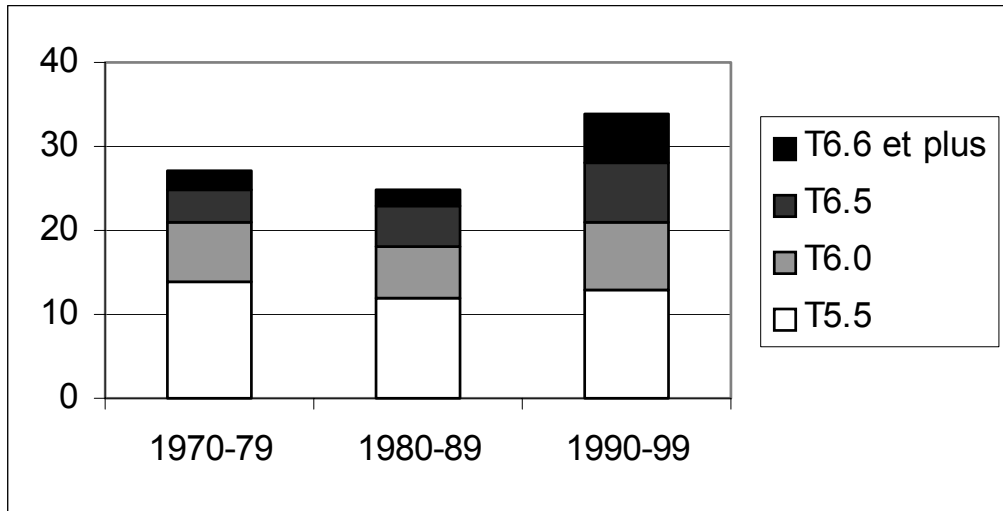


Fig 2.6.3: Decadal distribution of the number of intense TCs for different categories (Dvorak classification) in the SWIO: Source: Chang-Seng, 2005; adapted from NCDC, 1999

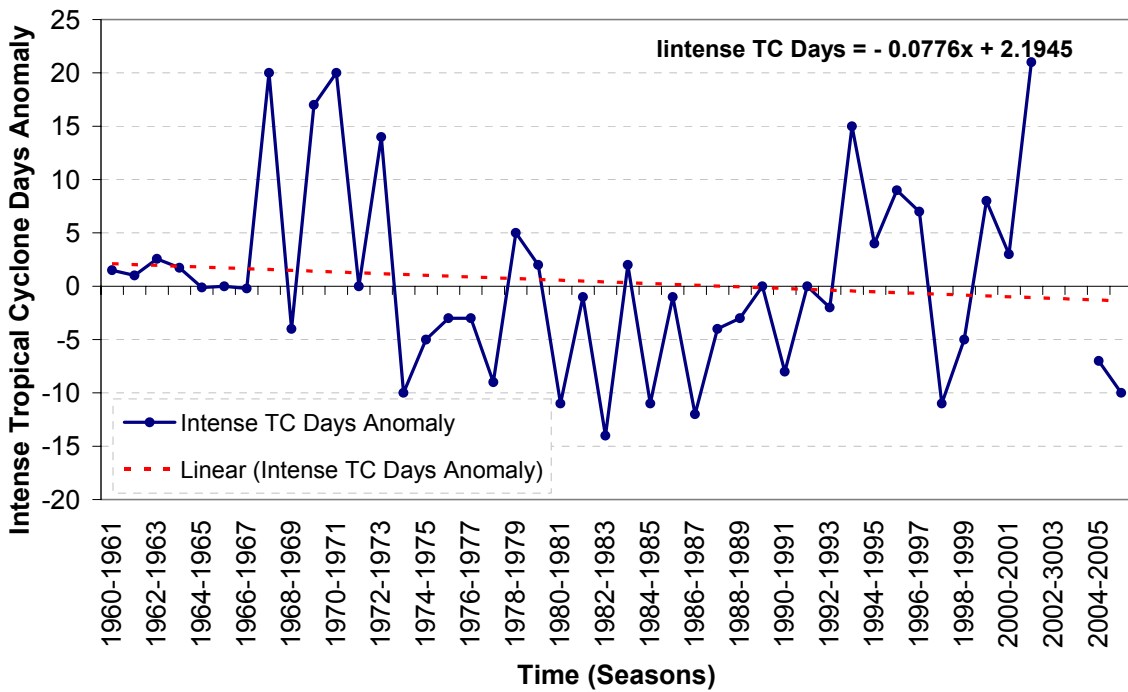


Fig 2.6.4: Intense tropical cyclone days anomaly time series in the SWIO

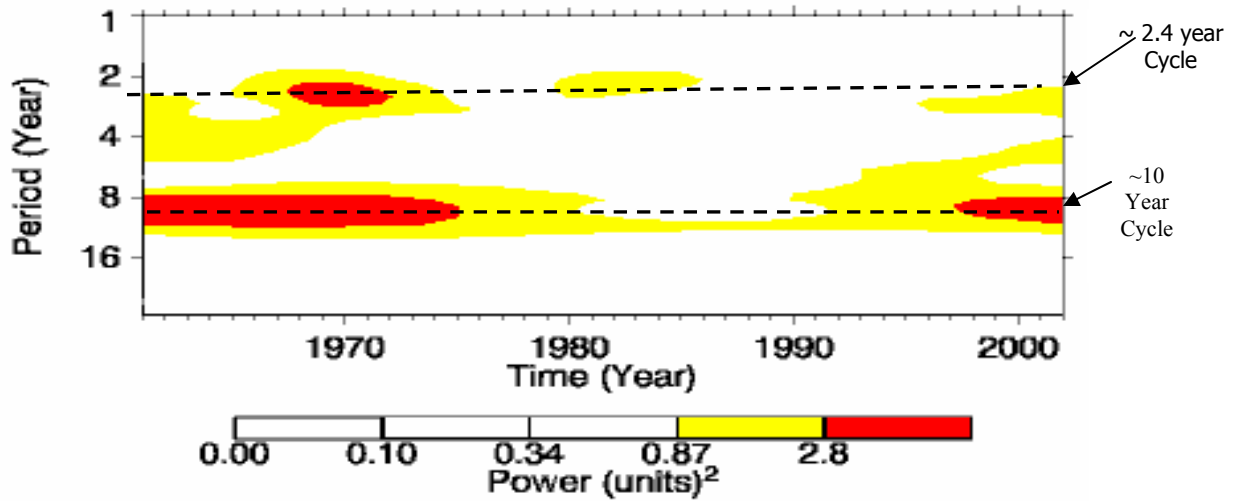


Fig 2.6.5: Wavelet power spectrum of Intense TC days time series index
(Source: Chang-Seng, 2005)

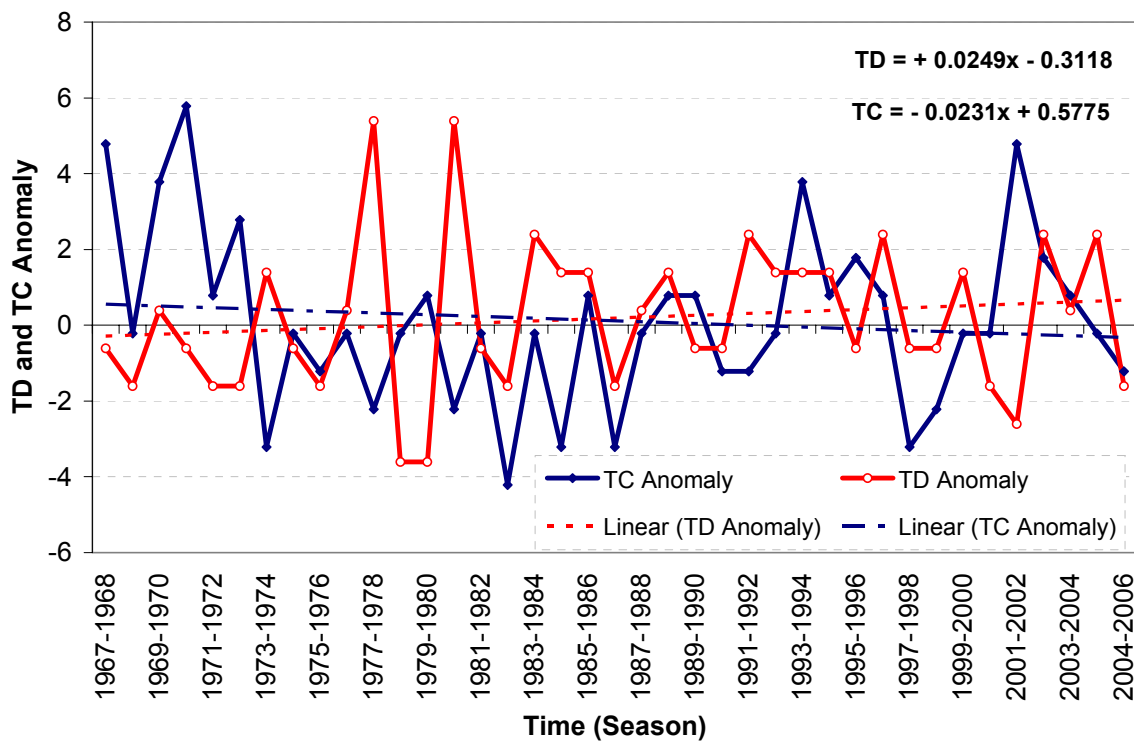


Fig 2.6.6 Time series index of tropical depressions and cyclones in the SWIO

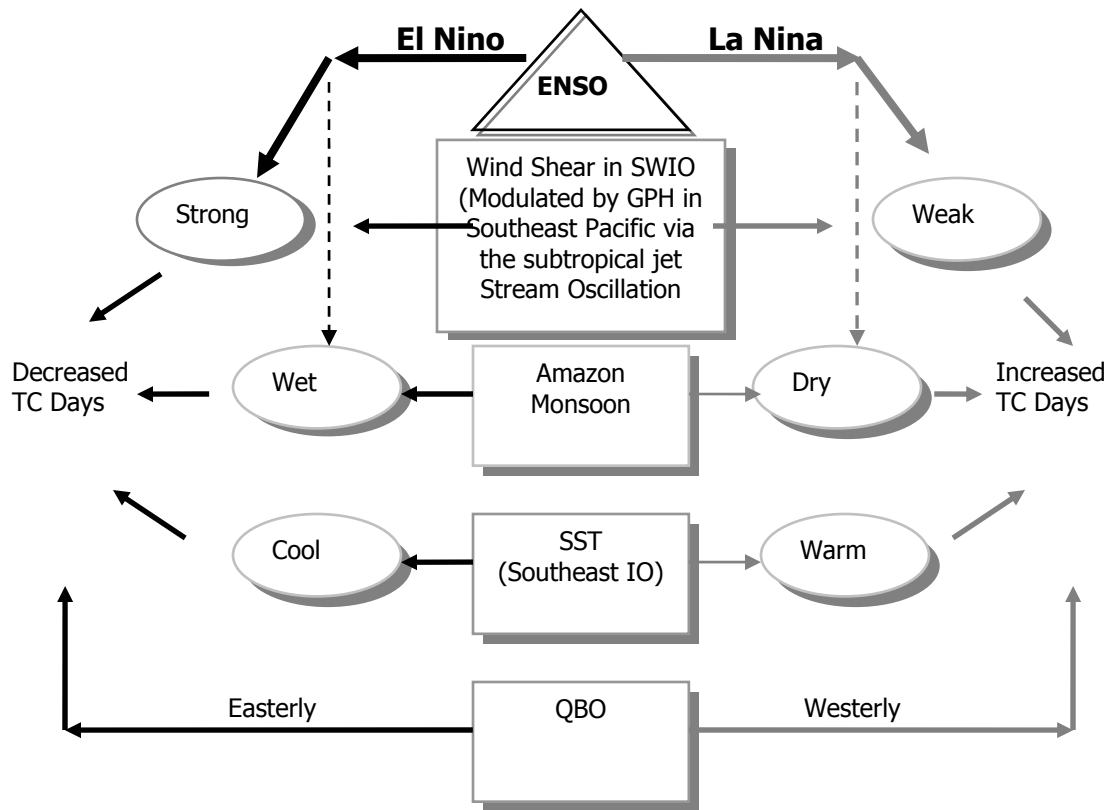


Fig 2.6.7: Schematic diagram shows mechanisms of intense TC Days variability in the SWIO (Source: Chang-Seng, 2005)

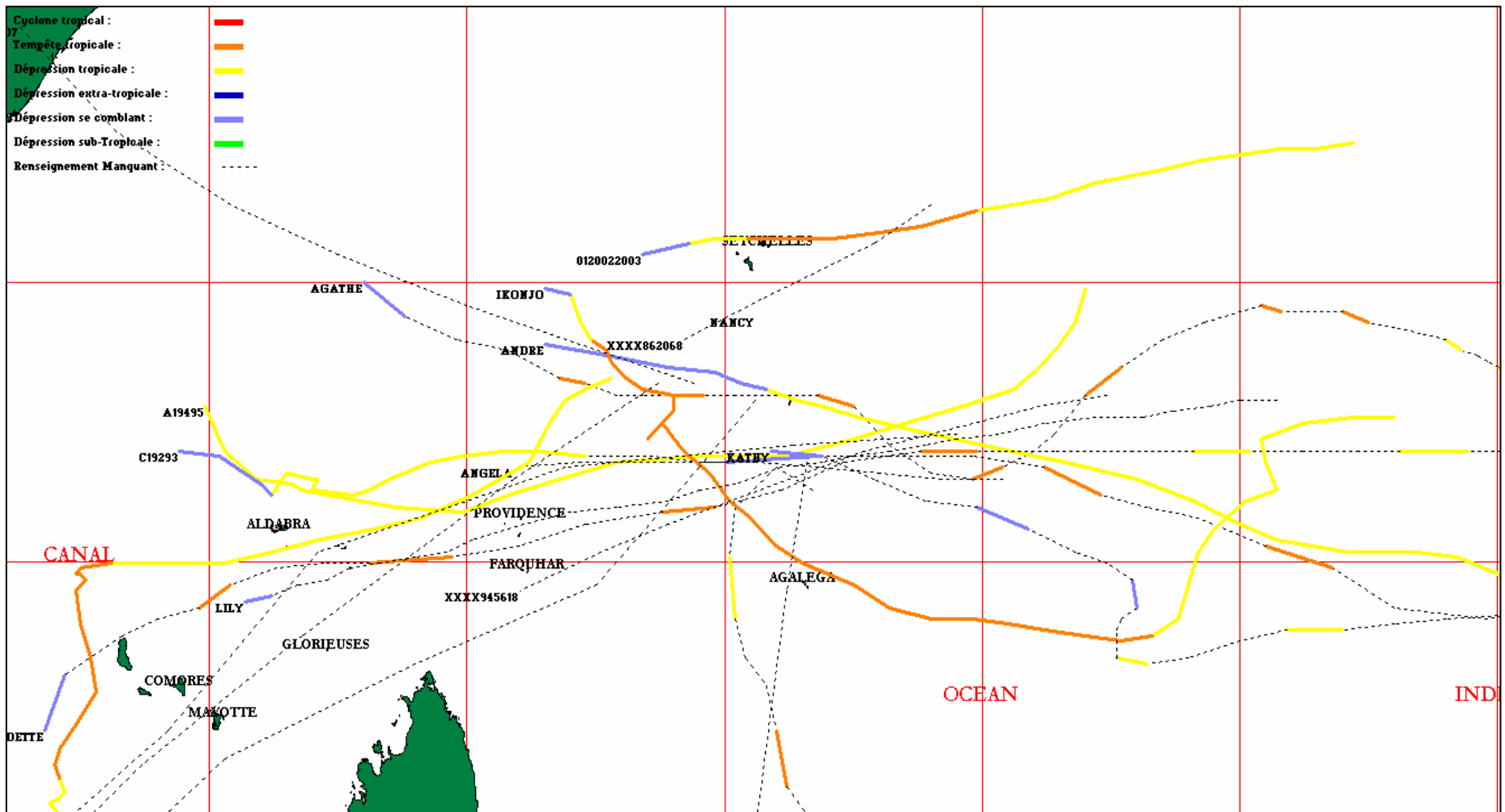


Fig 2.6.8: Historical tropical cyclone track in the Seychelles EEZ from 1847 to 2003

2.7 Impact of ENSO

Studies by Webster et al. (1999); Saji et al. (1999) and Camberlin et al. (2001) have suggested that strong seasonal ocean-atmosphere interaction modes are unique to the Indian Ocean climate system. Behera et al. (1999) and Vinayachandran et al. (2000) showed that there are internal dynamic and thermodynamic processes that lead to basin-scale air-sea interaction in the Indian Ocean. It has been claimed that an east-west dipole mode known as the Indian Ocean Dipole Mode (IODM) exists in SST in the tropical Indian Ocean which is independent of the El Nino signal. This condition can lead to increased equatorial easterly flow and excess rainfall in the western Indian Ocean and eastern Africa. In the section below the impact of ENSO on air, ocean temperature, rainfall, sea level and tropical cyclone is examined.

2.7.1 ENSO and Air Temperature

The underlying effect of the El Nino on the long term global trend is in favour towards warmer temperatures. However, two questions arise for which there are no clear answers at this point. 1) Exactly how much of the extreme rise in global temperatures during the 1997-98 periods was due to the 1997-98 El Nino, versus the contribution from the underlying long term trend? 2) Did the extreme El Nino occur in response to global warming trends? This second question ties into the first question. In fact, how global warming impacts onto natural modes of climate variability like El Nino, the Pacific Decadal Oscillation, and the North Atlantic Oscillation (all of which can have an affect on global air temperatures) is a very compelling research problem. The anomaly in maximum temperature during the 1997-98 period was averaged from +0.4 to +0.7 and +0.7 to +0.8°C in the JJA and DJF seasons respectively. Record temperatures have been recorded at the Seychelles International Airport in early 2007 following the moderate El Nino of the late 2006. During La Nina, air temperatures are anomalously cooler than normal ranging from -0.1 to -1.0°C.

2.7.2 ENSO, SST and Sea Level

It was also suggested that there was a strong decadal relationship between air temperature and SST in the Seychelles; hence it was recommended that further analysis is carried out to draw better conclusions (Payet et al., 2000). Therefore, the relationship between SST and air temperature is investigated using cross-wavelet modulus power spectrum analysis with the data filtered in the relatively low band between 1.5-16 years (fig 2.7.1 a). It is shown that the temperature at the Seychelles International Airport has strong cross power spectral energy at 3-4 year cycle with the 5 degree NCEP area SST around Mahe time series particularly between the 1982-90 and the 1996-2000 periods (fig 2.7.1 b). It is found that there is a strong positive relationship of correlation coefficient of +0.75 at a 3-4 year cycle rather than a decadal relationship. The governing force is found to be linked to both the ENSO event with a 3-5 year cycle as indicated in the peak cross power spectral energy and the ocean Rossby propagating wave which has a 3-year cycle. The time delay between SST and the near surface maximum temperature is small (fig 2.7.1 c). This suggests that SST and air temperature may not necessarily drive each other, but actually act as a coupled ocean-atmosphere system, particularly during strong ENSO years.

The record sea level rise anomaly of +32 cm on the 16th November 1997 was discussed in the Initial National Communication as a result of the 1997-98 El Nino event (Payet et al., 1998). In 2002, Chang Seng analyzed all Indian Ocean tide and sea surface temperature data during the peak of the sea level rise. The *temporary extreme* fluctuation in sea level topography was not only an effect of El Nino, but strongly linked to the coupling between the El Nino and Indian Ocean Dipole Mode (IOD). The Indian Ocean Dipole (IOD) is a climate mode that occurs inter-annually in the tropical parts of the Indian Ocean. Typical of climate oscillations, the IOD experiences a 'positive' phase and a 'negative' phase. During a positive IOD event, the sea-surface temperature (SST) drops in the southeastern part of the Indian Ocean; off the northern coast of Australia, the eastern coast of Japan and throughout Indonesia, while the SST rises in the western equatorial Indian Ocean; off the eastern coast of Africa from the northern half of Madagascar to the northern

edge of Somalia. Furthermore, convective patterns increase in the northern half of Africa, India and off the eastern coast of Africa. Inverse conditions exist during a negative IOD event. In other words, there was a large see-saw effect in the sea level, with the western Indian Ocean characterized by positive sea level elevation anomaly while the eastern side had a negative elevation anomaly. The lowest tide occurred on the 15th December 1993. The lowest tide is found to be linked to the 1993 La Nina event.

2.7.3 ENSO and Rainfall

The 1997/1998 El Nino caused catastrophic floods on Mahe. A record maximum of 480 mm of rain fell over a 24 hour period at Grand Anse, on Mahe Island, while the Seychelles International Airport reported a monthly record maximum of 694.1 mm as compared to the long-term mean of 107.1 mm (Seychelles Initial National Communication, 2000). In the same study, it was shown that the intense rain was caused by an easterly transient equatorial wave which was phase locked with an ocean Rossby propagating and amplifying wave just south of the inner islands. The driving mechanism as discussed above was the in-phase oscillation between the El Nino and the Indian Ocean Dipole Mode (IODM). Many forecast centers now use IODM in their routine forecast system.

It was also reported in the INC that rainfall had increased in both seasons as a result of El Nino while drought occurred during the La Nina period (Payet, 1998). However, Chang-Seng (2002) showed that El Nino/ La Nina actually cause a shift in seasonal rainfall pattern. In general, it is *more than likely than not* that below normal rainfall is observed in the rainy season (DJF) with the exception of January during the El Nino years. More than normal rainfall is *likely than not during* the dry season. August is *likely* to be wetter during El Nino years (fig. 2.7.2 to 2.7.5).

La Nina is *likely* (60-80%) to increase rainfall in January and February. However December is likely (90%) to observe a deficit in observed rainfall (fig 2.7.4 (b) (c)). It is *more likely than not that* during La Nina rainfall is suppressed in the early dry

season between June and July (fig 2.7.5 (a) and (b)), but the month of August is *likely* (90 %) to be wetter during La Nina episodes (fig 2.7.5 (c)).

Overall, the IPCC Fourth Assessment (FAR) concludes that more intense and longer droughts have been observed over wider areas since the 1979s, particularly in the tropics and subtropics. Changes in SST and wind patterns have also been linked to droughts.

2.7.4 ENSO and Tropical Cyclone

The conceptual model (fig 2.6.8) clearly shows that EL Nino events actually cause a decrease in intense tropical cyclone frequency while a mild La Nina type of signal causes an increase in intense tropical cyclone in the SWIO. It is well known that global sea surface temperatures have a strong influence on the cyclone activity. Normally, a warming in SST and heat content of the ocean surface layer would fuel cyclonic development. However, surprisingly there is a compromise between SST as a thermodynamic mechanism that fuels the development of cyclone and wind shear kinematic effects that govern intense tropical cyclone development. In warm ENSO (El Nino) years there is an increase in westerly winds at upper levels causing increased wind shear and reduced TC in many areas (Gray 1984 a, b; Shapiro, 1987; Chang-Seng, 2005). It is also observed that during El Nino/ La Nina, TCs are likely to track southwards/ westward respectively.

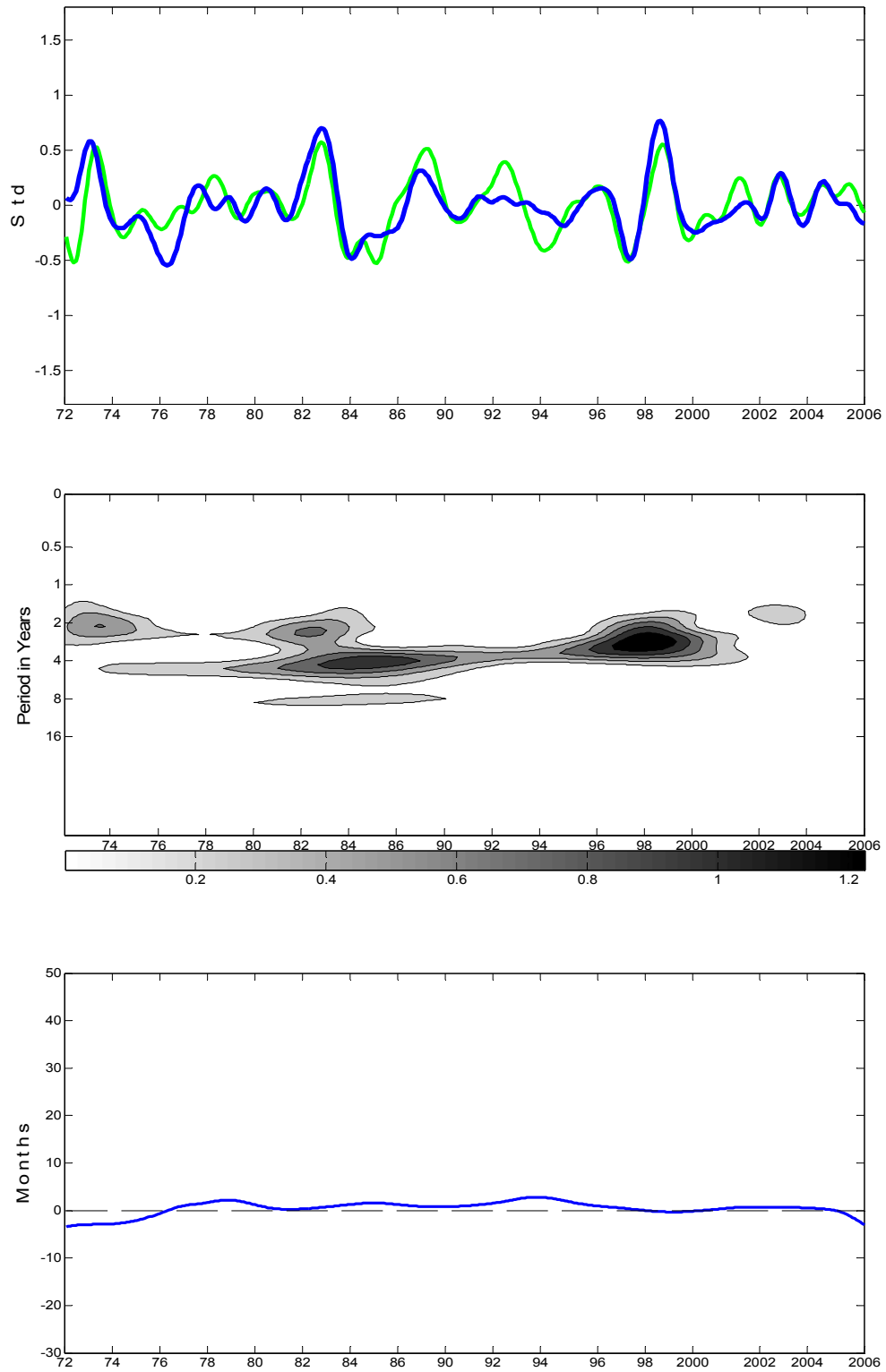


Fig 2.7.1: (a)Temporal evolution (b) co-spectral power and (c) time delay between SST(blue) and Airport maximum temperature(green) (Low band pass filter 1.5 -16 yrs)

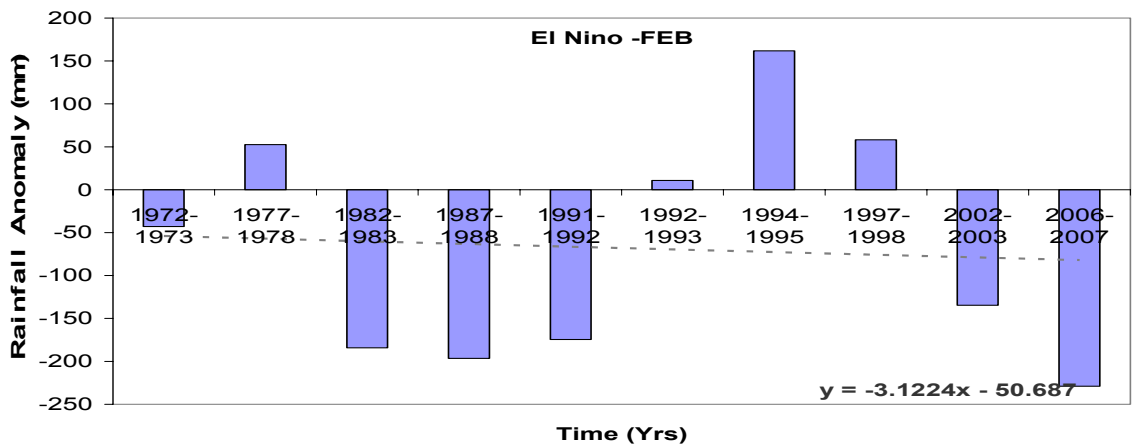
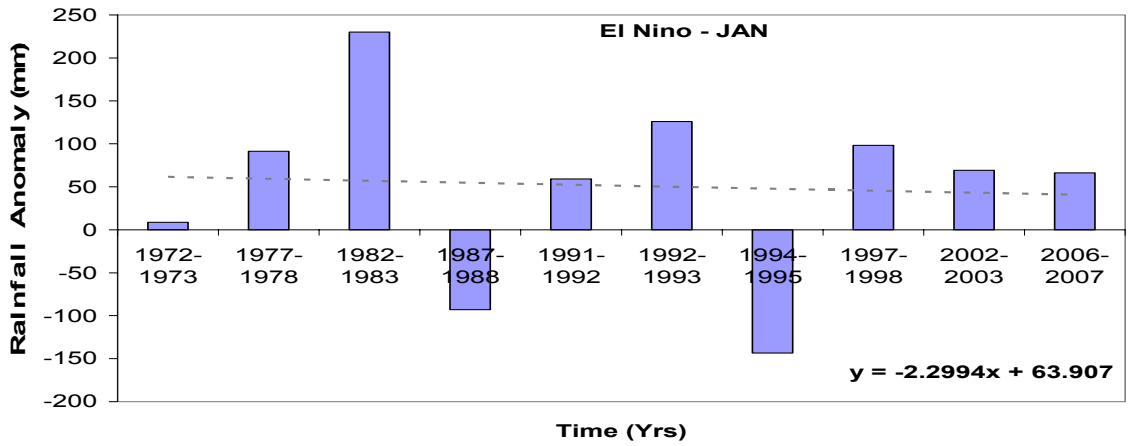
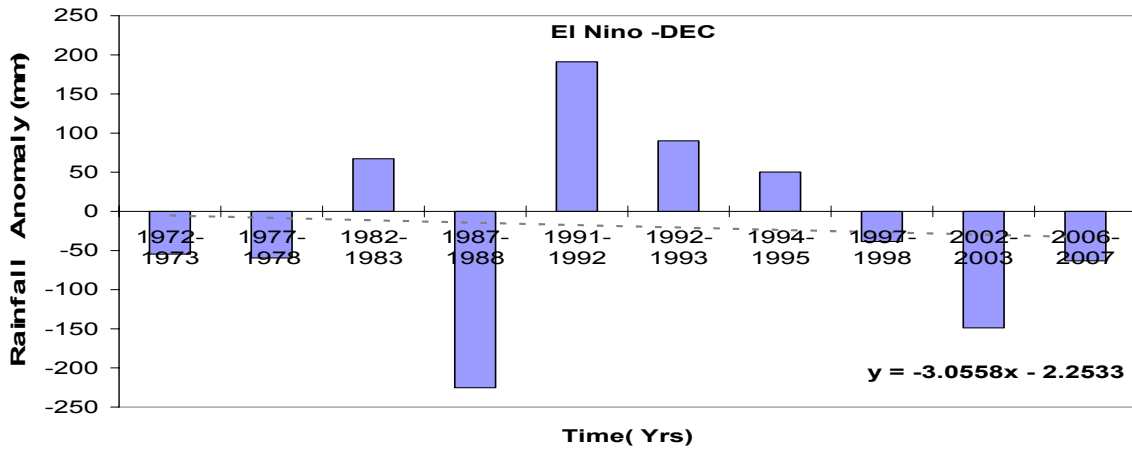


Fig 2.7.2: El Nino impact on monthly rainfall during the rainy season (Chang-Seng, 2002)

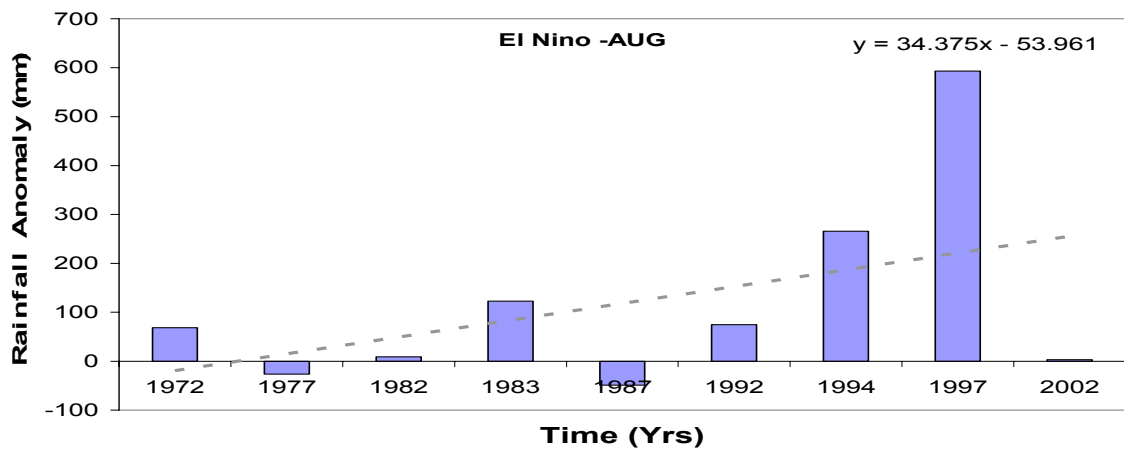
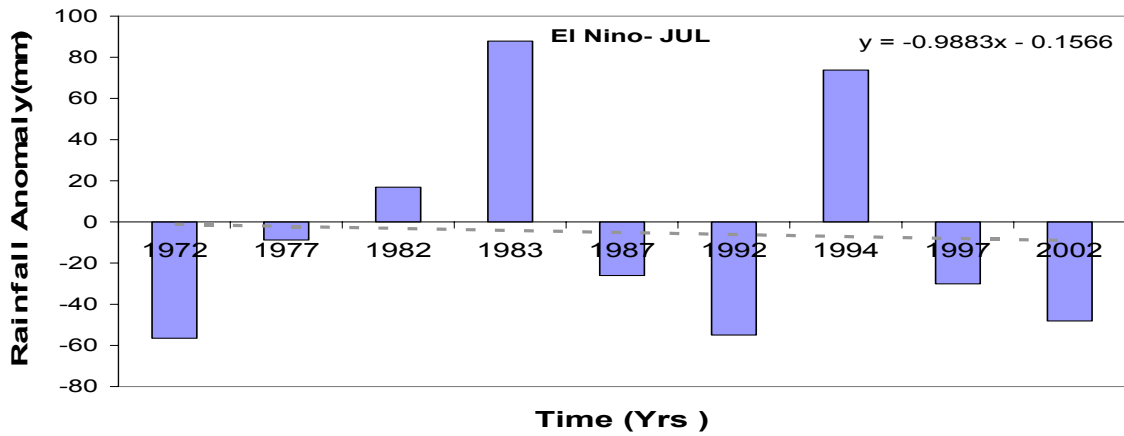
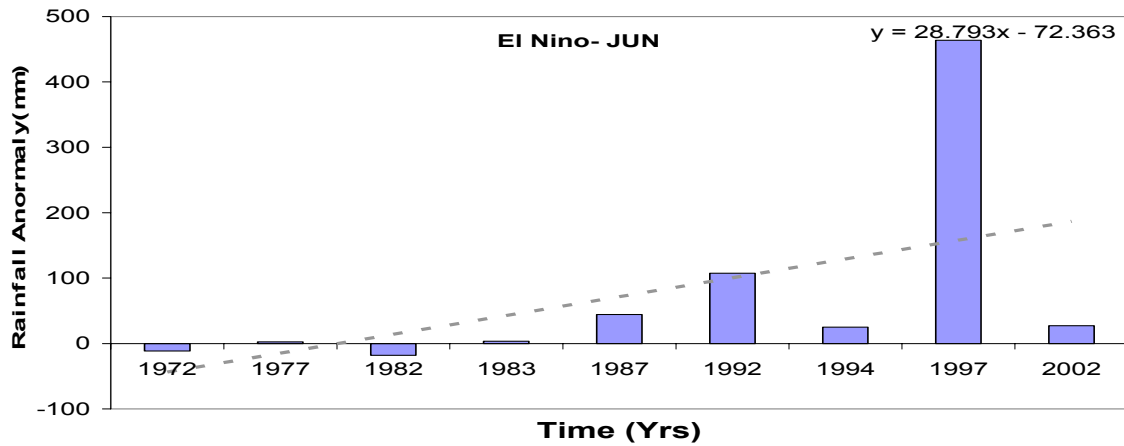


Fig 2.7.3: El Nino impact on monthly rainfall during the dry season (Chang-Seng, 2002)

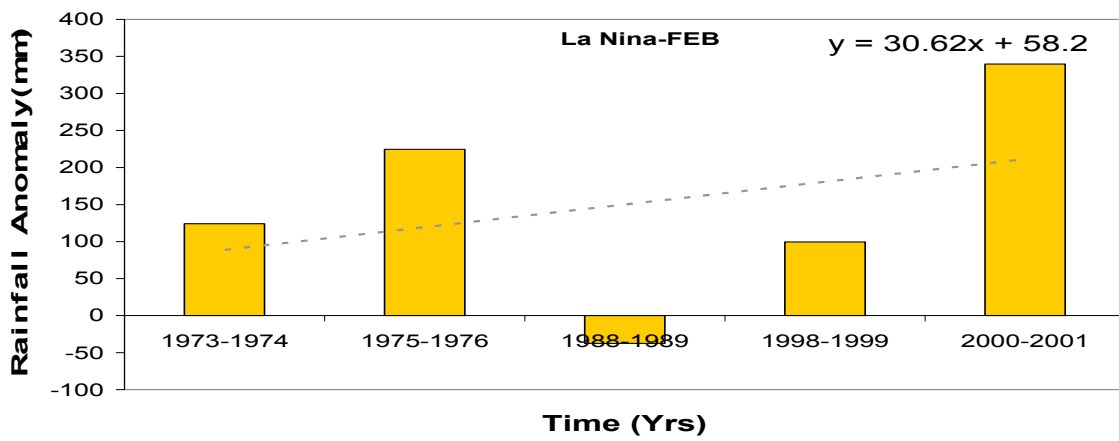
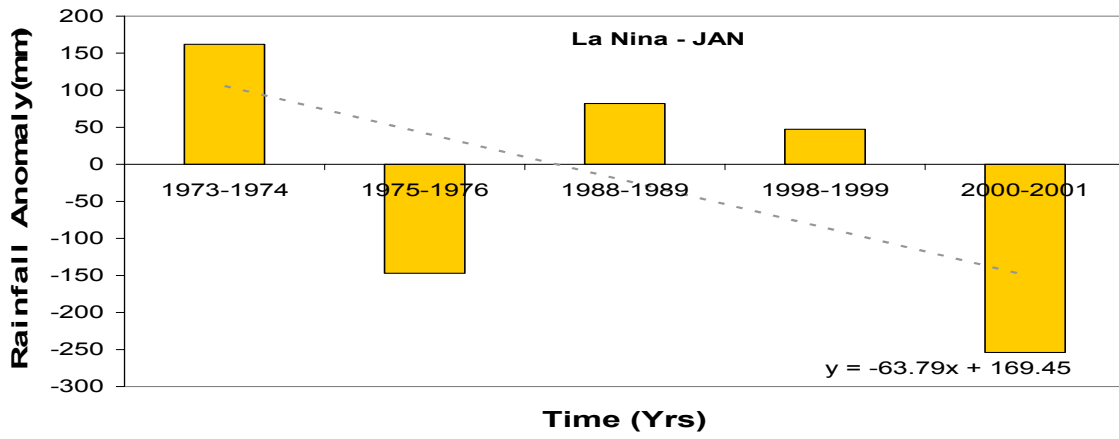
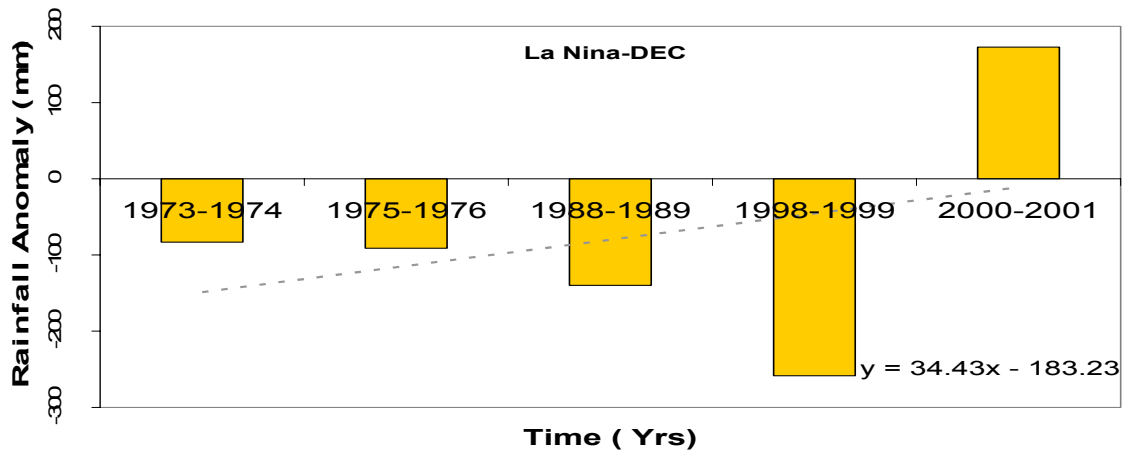


Fig 2.7.4: La Nina impact on monthly rainfall during the rainy season (Chang-Seng, 2002)

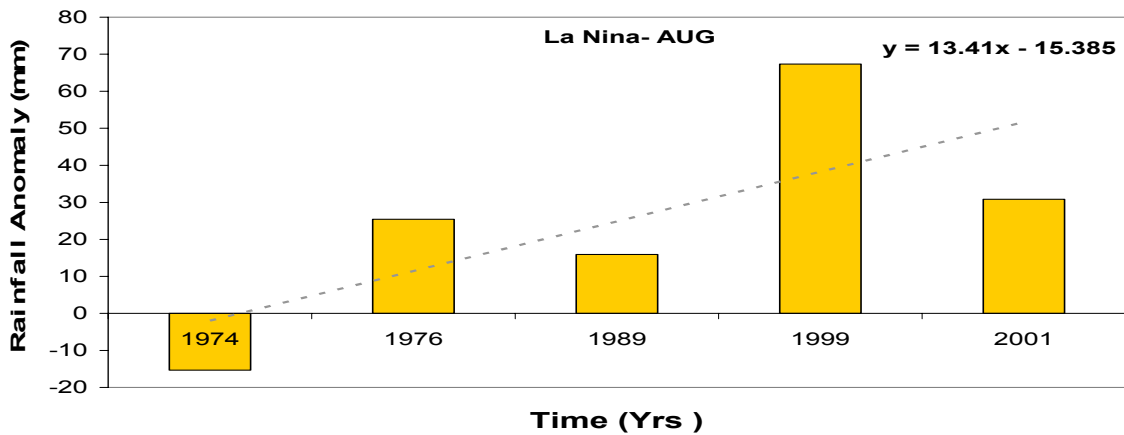
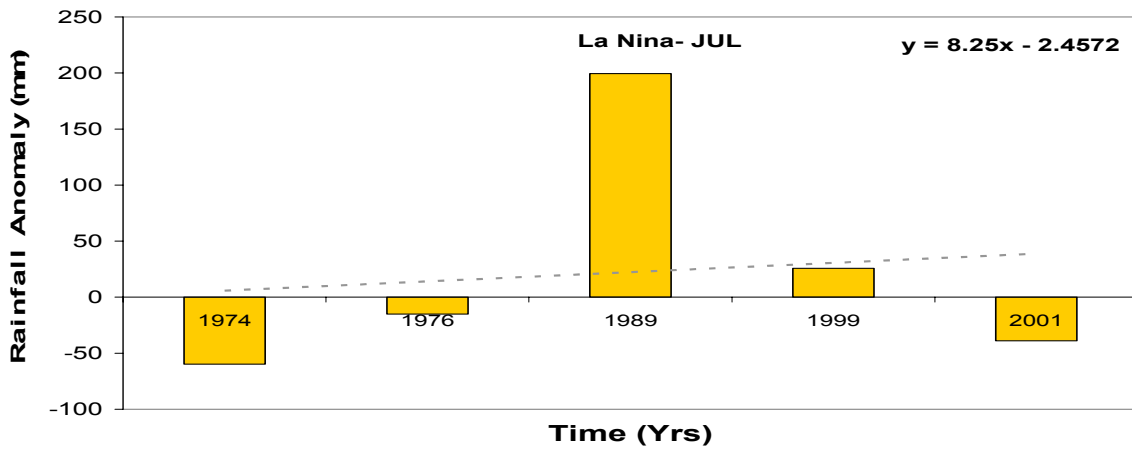
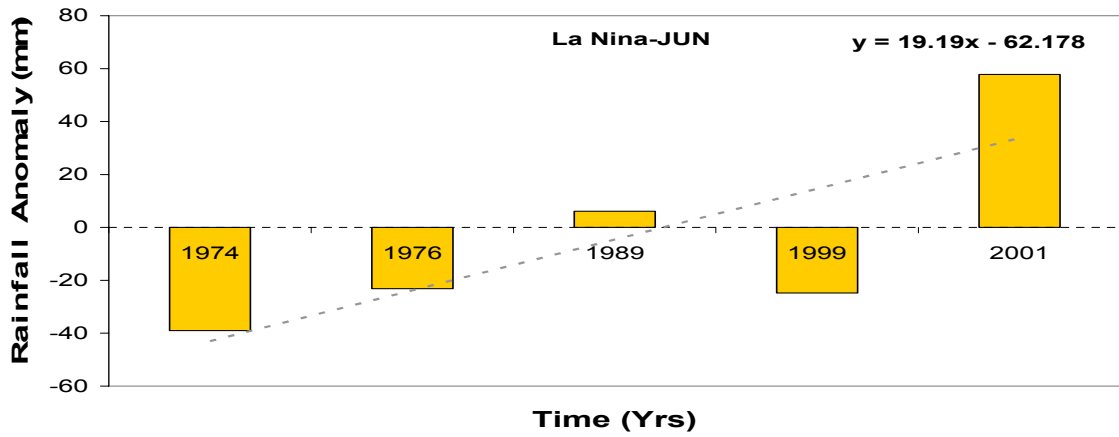


Fig 2.7.5: La Nina impact on monthly rainfall during the dry season (Chang-Seng, 2002)

3.0 Paleo-Climate Changes

Little is known about the Paleo-climate conditions of the Seychelles. Sedimentological evidence supports the hypothesis that drier rather than wetter conditions prevailed during the late Pleistocene period (Heitzler, 1977). It was reported in the INC that markedly higher rainfalls occurred on Mahe before 1905 and that lower rainfall occurred between 1923 to 1939 and 1959 to 1970.

In a recent field experiment, oxygen isotope (O_{18}) was extracted from a 3-meter *Porites lutea* coral colony collected from Beau Vallon Bay, Mahe Island, in July 1995 by Hunter from Scripps Institution of Oceanography. Values are in standard per mil notation relative to PDB and measurement precision is better than 0.08 mil notation relative to PDB. Ages were derived from annual variations in the oxygen isotope in conjunction with annual density banding. The monthly coral isotope is one of the longest environmental finger print data available that can be used as a proxy of longer climate trends in the Seychelles. High concentrations of oxygen isotope are normally linked to high rainfall and river flow. The smooth curve is the 10-year filtered data (fig 3.3.1).

Figure 3.3.2 shows the Seychelles coral isotope versus the Climate Reserch Unit (CRU) observed SST 10-year filtered time series with respective quadratic trend. Correlation anayisis suggests no conclusive link between the coral isotope and CRU SST, but there is a consistent upward trend in SST and the coral isotope, suggesting that the climate has an upward warming trend and is possibly related to wetter climate period. Another coral time series of oxygen isotope index from the 1840-1994 period was extracted in April 1994 from a large *Porites solida* colony growing in a water depth of 9-meters off the northeast coast of Mahe'. It has a strong correlation with historical SST with the Arabia and Indian seas, suggesting trends can be linked and related to Nino3.4 area in the Pacific Ocean at decadal time scales (Charles, 1998; Feiffer et al., 2005).

It is noted that the proxy data such as tree rings, and coral samples may be influenced by both local temperature and other factors such as precipitation, and are

often representative of particular seasons rather than full years. Uncertainties also increase with time due to limited spatial coverage. Nevertheless, paleo-climate information supports the warming of the last half century and it has been unusual for at least the previous 1300 years (FAR, 2007).

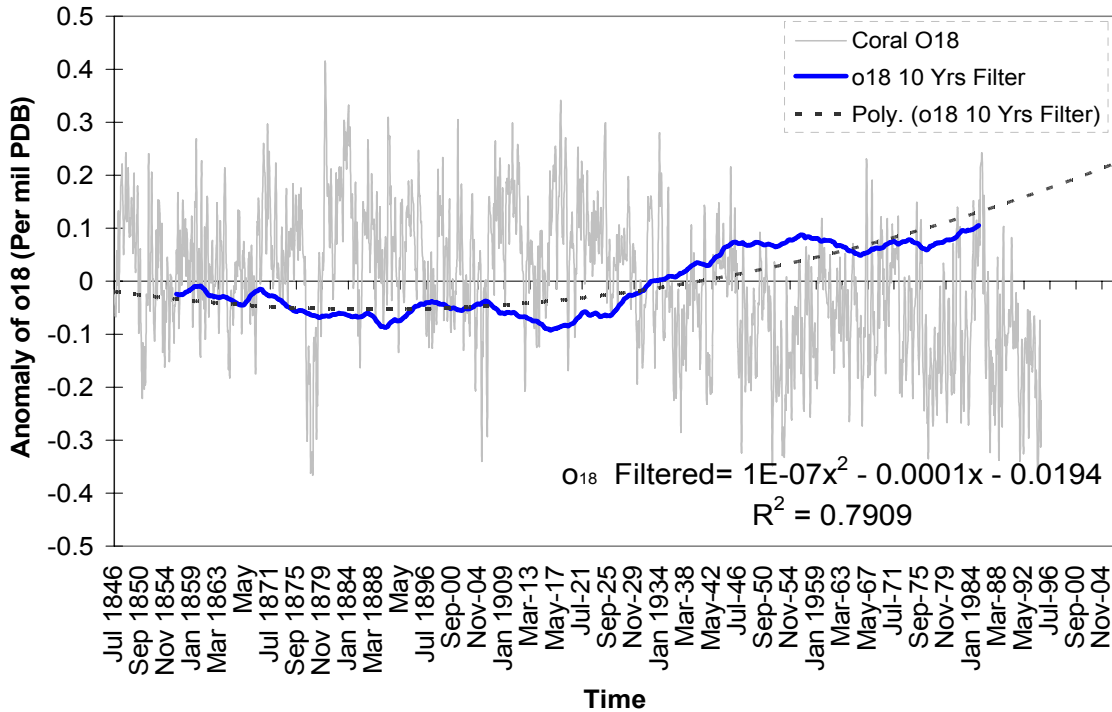


Fig 3.3.1: Time series of Seychelles Coral Isotope (O18). The smoothed curve is the 10-years filter with a quadratic trend

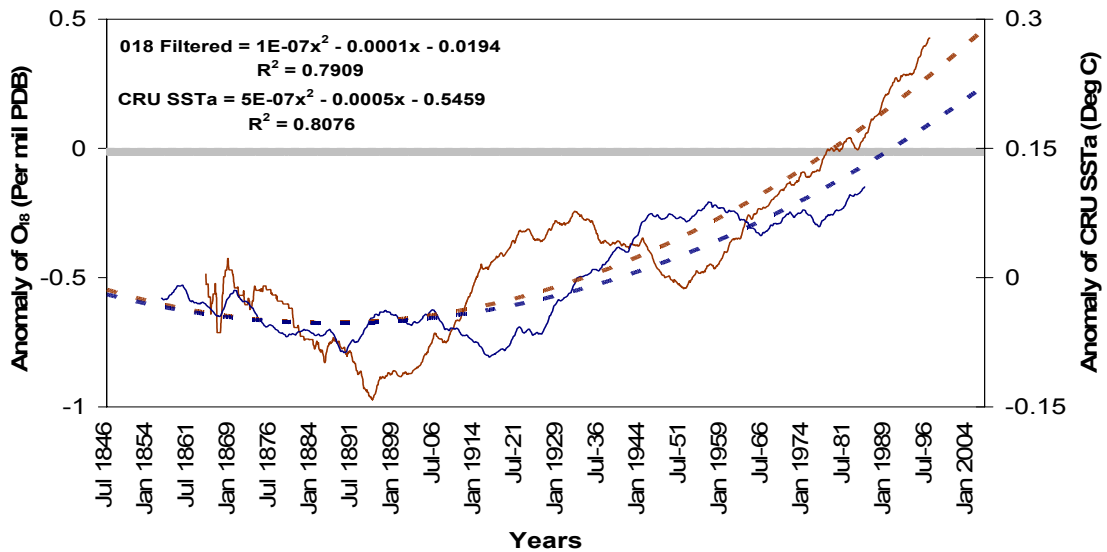


Fig 3.3.2: Seychelles coral isotope versus CRU observed SSTa 10-year filtered time series with respective quadratic trend.

4.0 Summary

The trends and characteristics of the Seychelles climate are assessed by analyzing various short terms (1972-2006) and longer term data sets. Overall, the latest temperature trends based on maximum and minimum temperature show warming between +0.33 to +0.82°C respectively and are significantly warmer than previously assessed in the Initial National Communication. The minimum temperature is warming faster than maximum temperature as a result of the 'urban island heat' effect and the warming is higher during the southeast monsoon. The 2007 monthly average maximum temperature observations show record warming of +1.7, +2.5 and +1.3°C for January, February and March respectively compared to the 1972-1990 period. The record warming in temperature is attributed to a number of factors such as the development of a moderate El Nino late in 2006, an active cyclone season to the northeast of Madagascar, a pronounced positive phase of the Madden Julian Oscillation (MJO) suppressing cloud development in the southwest Indian Ocean and the potential increasing background effect of the green house global warming. The ENSO influence on global rise in air temperature is complex and not clearly understood. The warming in air temperature is also reflected in the longer-term data sets.

The linear trend of the SST data available at the Seychelles International Airport suggests a gradual cooling in SST since 2000; however no firm conclusions can be drawn from such limited data set. The Climate Research Unit's (CRU) SST data and observed air temperature have a strong positive relationship at a 3-4 year cycle rather than a decadal relationship as suggested initially (Payet et al., 1998). The governing force is found to be linked to both the ENSO and the Rossby wave mechanisms (Chang-Seng, 2005). Paleo-climate studies support the hypothesis that drier rather than wetter conditions prevailed during the late Pleistocene period (Heirtzler, 1977). Recently, it was found that the coral isotope (O_{18}) extracted from corals at Beau-Vallon Bay, Mahe, Seychelles and the CRU SST have a consistent upward trend suggesting a warming and a potential wetter climate trend.

The annual sea level trend anomaly is +1.46 mm per year with a standard error of ± 2.11 mm per year. Most stations in the southwest Indian Ocean are reporting a similar positive trend particularly in the Mauritius and Reunion area. On the other hand, satellite altimetry shows negative sea level in the southwest Indian Ocean from 1993. Therefore, there is no firm evidence of forced sea level rise. The local sea level trends are rather consistent with the global average sea level rise with an average rate of +1.8 mm (1.3 to 2.3 mm) per year over the 1961 to 2003 period. According to the FAR (2007), the underlying cause of sea level rise is due to the decline of mountain glaciers and snow cover in both hemispheres and the expansion of sea water through thermal warming of the ocean. The 1997-98 periods' abnormal extreme events in sea level and rainfall were not only due to the El Nino (Payet et al., 1998), but there was a coupling between the El Nino and Indian Ocean Dipole Mode (Chang-Seng, 2002). It was characterized by a drop in SST in the southeastern part of the Indian Ocean while the SST rose in the western equatorial Indian Ocean, causing ocean thermal expansion and rise in regional and local sea level.

Therefore, coastal erosion and inundation impacts may also be viewed as a result of *EL Nino, Indian ocean Dipole (IOD) superimposed on other normal phenomena such as "cyclonic" generated swell-storm surge and spring tides; all colluding coincidentally to create an abnormal impact* as was the case towards in the end of the second week of May 2007.

On the other hand, the lack of expertise to integrate modeling and detailed assessment in increasing coastal developments may change coastal dynamics and processes which may only have negative impacts on the environment.

In addition, the impact of ENSO (El Nino/ La Nina) causes a significant shift in seasonal rainfall pattern rather than an overall increase in both seasons as suggested by Payet et al., 1998. The rainy season is *more likely than not* to be relatively dryer while the dry season is more likely than not to be wetter during El Nino and vice versa for La Nina years (Chang-Seng, 2002).

The dry season is characterized by wetter conditions compared to the 1972-90 period. The spatial variability of rainfall shows that most areas are wetter than

normal in both seasons and annually, with the exception towards the southwest of Mahe. Heavy rainfall events have been the major contributor to the increase in rainfall (Lajoie, 2004). However, the filtered annual rainfall data have a surprising downward rainfall trend. The long term trend of a merged 119-year monthly rainfall data confirms strong rainfall variability over Mahe, Seychelles. It is characterized by distinct 2-4, 10 and 30-year cycles. The 2-4 year cycles are linked to the ENSO, biennial cyclone variability and the QBO (Chang-Seng, 2005). The decadal rainfall cycle is linked to the sunspot cycle (Marguerite, 2001) and the decadal variability in intense tropical cyclone (Chang-Seng, 2005). One of the most interesting and important findings of this assessment is the detection of the 30-year cycle characterized by periods of abnormally high and low rainfall trends operating as a background low climate signal. It is suggested that the 30-year natural cycle has gradual, but significant influence on the long term climate variability in the Seychelles. It is proposed that the 30-year cycle in rainfall is tele-connected to the Atlantic Multi-Decadal Oscillation in sea surface temperature through the ocean thermohaline circulation which distributes heat globally. Although the long term annual rainfall shows an upward trend in rainfall of +2mm per year, it is also clear that the upward trend is not consistent or maintained when the data is filtered further.

Studies by Hoareau (1999) have suggested an increase in intense TCs in the SWIO for the decades 1970-79 and 1990-99, while a decrease in that of the 1980-90. However, in a recent study (Chang-Seng, 2005) it was shown that the decade 1960-69 was the most active in intense tropical cyclone days in the SWIO. In addition, the linear trend is negative with a decreasing rate of 0.14 intense tropical cyclone day per year in the southwest Indian Ocean from 1960 to 2005. It was also found that intense TCs are characterized by biennial to decadal cycles that are related by Quasi Biennial Oscillation and the decadal variability in the deep ocean thermohaline circulation respectively. Furthermore, tropical cyclone has decreased at a rate of -0.023 tropical cyclone day per year. In contrast, the number of tropical depression has an upward trend of +0.025 tropical depression per year possibly linked to a warming in SST in the south central Indian Ocean. The recent tropical cyclone direct impacts on the Seychelles portrays that the cyclonic belt and risks area is widening possibly associated with global warming. However, there is simply

no firm evidence to draw such conclusions due to lack of data and scientific research. There were similar TC strike probabilities in the past caused by 'anomalous' variation in weather patterns (Parker and Jury, 1999; Chang-Seng, 2005) occurring at the time. The ENSO impact on tropical cyclone activity shows that EL Nino characterized by anomalous SST warming favours less intense tropical cyclone while mild La Nina is favourable for an increase in intense tropical cyclone in the SWIO. There is a compromise between SST and wind shear effect on intense TC development (Gray 1984 a, b; Shapiro, 1987; Chang-Seng, 2005). TCs are likely to track westward during La Nina and southwards during El Nino.

Overall, temperature trends show warming between +0.33 to +0.82°C in maximum and minimum temperatures respectively. The minimum temperature is warming faster than maximum temperature as a result of the 'urban island heat' effect. There are strong air and sea surface temperature interactions at 3-4 year cycle. Coral isotope (O18) extracted from corals at Beau-Vallon Bay, Mahe, Seychelles and the SST have a consistent upward trend suggesting a warming and a potential wetter climate trend. The annual sea level trend anomaly is +1.46 mm per year with a standard error of ± 2.11 mm per year. Most stations in the southwest Indian Ocean are reporting a positive trend in sea level, however satellite altimetry shows negative sea level in the southwest Indian Ocean from 1993. Therefore, there is no firm evidence of forced sea level rise. El Nino, Indian Ocean Dipole Mode (IOD) and other phenomena such as "cyclonic" generated swell-storm surge and spring tides may collude to cause extreme impacts. The impact of ENSO (El Nino/ La Nina) causes a significant shift in seasonal rainfall pattern. Both the temporal and spatial rainfall from the 1972-2006 periods over Mahe is characterized by wetter conditions compared to the 1972-90 period. Heavy rainfall events have been the major contributor to the increase in rainfall. The longer merged 119-year monthly rainfall data have no significant trends in rainfall but are characterized by distinct 2-4, 10 and 30-year cycles. The 30-year cycle in rainfall has a significant influence on the long term climate variability in the Seychelles. Intense tropical cyclone and tropical cyclone have a decreasing rate from the 1960 to the 2005 period. In contrast, the number of tropical depression has an upward trend possibly linked to the warm pool in sea surface temperature in the south central Indian Ocean. On the other hand,

there is simply no firm evidence to draw conclusions on changes in cyclonic risks areas. The ENSO impact on tropical cyclone activity shows that EL Nino characterized by anomalous SST warming favours less intense tropical cyclone while mild La Nina favours an increase in intense tropical cyclone in the SWIO. There is a compromise between SST and wind shear effect on intense TC development.

Reference List

- Behera, S. K., Salvekar P. S., and Yamagata T., 1999: Simulation of Interannual SST Variability in the Tropical Indian Ocean, *Amer. Meteorol. Soc.*, **13**: 3487-3498.
- Chang-Seng, S. D., 2002: El Nino and Indian Ocean Dipole Mode and its Impact on Sea Level and Rainfall in the Seychelles, Seychelles National Meteorological Services.
- Chang-Seng, S. D., 2005: Marine Weather Systems, Tropical Cyclone Prediction and Impacts in the Southwest Indian Ocean, MSc. Thesis, Department of Geography and Environmental Studies, University of Zululand.
- Charles, C. D et al, 1997: Interaction between the ENSO and the Asian Monsoon in a Coral Record of Tropical Climate, *SCIENCE*, VOL. 277 , 15 AUGUST 1997
- Climate Change, 2007: The Physical Science Base, Summary for Policy Makers. Contribution of Working Group 1 to the Fourth Assessment Report (FAR) of the IPCC, 5th February 2007.
- Goldenberg, S. B., and Shapiro L. J., 1995: Physical Mechanisms for the Relationships between El Nino, West African Rainfall, and North Atlantic Major Hurricanes. *J. Climate*, (in press).
- Gray, W. M., 1968: Global View of the Origin of Tropical Disturbances and Storms. *Mon. Wea. Rev.*, 96: 669-700.
- Gray, W., 1984a: Atlantic Seasonal Hurricane Frequency. Part I: El Nino and 30 mb Quasi-Biennial Oscillation Influences. *Mon. Wea. Rev.*, 112: 1649-1668.
- Gray, W., 1984b; Atlantic Seasonal Hurricane Frequency. Part II: Forecasting its Variability. *Mon. Wea. Rev.*, 112: 1669-1683.
- Gray, W. M., Sheaffer J. D., and Lansea C. W., 1997; Climate Trends Associated with Multi Decadal Variability of Atlantic Hurricane Activity. Hurricanes, Climate and Socioeconomic Impacts, edited by H. F. Diaz and R. S. Pulwarty, Springer, Berlin, 15-53.
- Hoareau, K., 1999: La Fréquence des Cyclones Tropicaux Intenses dans le Sud-Ouest de L'ocean Indien (1970-1999). *Publications de l'Association Internationale de Climatologie*, **12**: 405-413.
- Jury, M. R., and Parker B. A., 1999: Synoptic Environment of Composite Tropical Cyclones in the South-West Indian Ocean. *S. A. J. Marine Sci.*, **21**: 99-115.
- Lajoie, F. R., 2004: WMO/CLIVAR ETCCDMI African Workshop on Extremes, Report for Seychelles

Leuliette, E. W., Nerem, R. S., and Mitchum, G., 2004: Results of TOPEX/Poseidon and Jason Calibration to Construct a Continuous Record of Mean Sea Level, *Mar. Geod.*, In Press.

Marguerite., T. M., 2001: Solar activity long term influence on Seychelles rainfall, Meteorological Services, Seychelles

Marguerite., T. M., 2007: Preliminary Results: Extreme Variability over the Seychelles Airport during the last 35 years, Meteorological Services, Seychelles

National Climate Data Center (NCDC), 1999: Global Tropical Cyclone Data Set (1967-1999), Asheville, North Carolina.

Payet, R.A.(Ed), 1998: Vulnerability Assessment of Seychelles to Climate Change, ENVIRO; Government of Seychelles..

Payet, R.A., (1999): Policy Implications of the Recent ENSO Events in a Small Island and Climate Change Context: Seychelles

Pfeiffer, M. et al, 2005: Monsoon-Induced Cooling of the Western Equatorial Indian Ocean as Recorded in Coral Oxygen Isotope Records from the Seychelles Covering the Period of 1840–1994AD; Leibniz Institut für Meereswissenschaften Kiel, IFM-GEOMAR, Wischhofstrasse 1-3, 24148 Kiel, Germany

Ragoonaden, S., 2006: Sea Level Activities and Changes on the Island of the Western Indian Ocean, Western Indian Ocean (WIOMSA), *Mar. Sci.* Vol.5, No.2, pp179-194

Saji, N. H., Goswami B. N., Vinayachandran P. N., and Yamagata T., 2001: A Dipole Mode in the Tropical Indian Ocean. *Nature*, **401**: 360-363.

Shapiro, L. J., 1989: The Relationship of the Quasi-Biennial Oscillation to Atlantic Tropical Storm Activity. *Mon. Wea. Rev.*, 117: 1545-1552.

Stoddart, D. R., and Walsh, R.P.D., (1999): Long Term Climate Change in the Western Indian Ocean. *Phil. Trans.R.Soc.Lond.* B.286:11-23

Vinayachandran, P. N., Lizuka S., and Yamagata T., 2002: Indian Ocean Dipole Mode Events in an Ocean General Circulation Model. *Deep-sea Res.*, **49B**: 1573-1596.

Walsh, R. P. D., 1993: Climate of the Seychelles, 39-58pp.

Webster, P. J., Moore A. M., Loschnig J. P., and Leben R. R., 1999: Coupled Ocean-Atmosphere Dynamics in the Indian Ocean During 1997-1998, *Nature*, **401**: 356-360.

