HONG KONG OBSERVATORY

Technical Note No. 104

Seasonal Forecasting for Hong Kong
- A Pilot Study

by
W.L. Chang and K.H. Yeung

Published March 2003

Prepared by

Hong Kong Observatory
134A Nathan Road
Kowloon
Hong Kong

551.509.33(512.317)

CONTENTS

CONTENTS (cont’ d)

List of Figures

List of Figures (cont’ d)

List of Figures (cont’ d)

List of Tables

List of Tables (cont’ d)

Executive Summary

S1. Seasonal forecasts, also known as long range weather forecasts or short range climate forecasts, are predictions of the average weather condition a month to about a year ahead. The purpose of these forecasts is to facilitate the planning of climate sensitive activities.

S2. Since the mid-1970s, the Hong Kong Observatory had been providing forecasts of the annual rainfall in Hong Kong to the Water Supplies Department for fresh water management purpose. These forecasts were stopped in 1998 because of the declining correlation between the predictor used at that time and the annual rainfall.

S3. The exceptionally heavy rain in 1997 coincided with the occurrence of one of the strongest El Niño events in the 20th century, while the landfalling over Hong Kong by 4 tropical cyclones in 1999 coincided with one of the strongest La Niña events in the 20th century. These anomalous climate phenomena stirred community interest in the possible link between El Niño/La Niña events and local climate, and gave impetus for the Hong Kong Observatory to provide a seasonal forecasting service to the community of Hong Kong.

S4. To this end, the Hong Kong Observatory undertook at the end of 2000 a 2-year pilot study on seasonal forecasting in Hong Kong. The objective of the pilot study was to examine the feasibility of making seasonal forecasts for Hong Kong. The scope of the study was to investigate the predictability of the number of tropical cyclones affecting Hong Kong in a year and the annual rainfall in Hong Kong, the two elements most closely related to the well being of the community and in which the community has shown the most interest. The approach taken in the investigation was the identification of climate factors impacting on the number of tropical cyclones affecting Hong Kong in a year and the annual rainfall in Hong Kong, development of forecasting techniques, formulation of experimental seasonal forecasts and the verification of these forecasts. The predictability of the time of onset of the tropical cyclone season in Hong Kong, an element on which the community has also shown an interest, was also examined but not to the point of formulating forecasts.

S5. The pilot study has found that the main factor influencing the number of tropical cyclones affecting Hong Kong in a year, the annual rainfall and the time of onset of the tropical cyclone season in Hong Kong is the El Niño/La Niña phenomenon, also known as the El Niño-Southern Oscillation (ENSO) phenomenon, which is characterized by large scale warming/cooling of the equatorial eastern and central Pacific. For the time of onset of the tropical cyclone season in Hong Kong, the Quasi-Biennial Oscillation (QBO), an oscillation in which the wind direction in the upper atmosphere over the tropics changes from east to west and then back to east every two to two and a half years, has also been found to be influential. For the annual rainfall in Hong Kong, the strength of the monsoon in the preceding winter was also found to be an important climate factor. Statistical relationships between the elements of interest and the climate factors were established using historical data.

S6. Techniques to forecast the number of tropical cyclones affecting Hong Kong in a year and the annual rainfall in Hong Kong were developed using the statistical relationships found. Experimental forecasts of these two elements for 2001 and 2002 were formulated and issued to the public. Verification against the actual conditions has shown that some skill exists in the forecasting techniques. Advantage should therefore be taken of the predictability found to provide to the community seasonal forecasts of the number of tropical cyclones affecting Hong Kong in a year, the annual rainfall in Hong Kong and the time of onset of the tropical cyclone season in Hong Kong. More detailed findings in support of the above conclusion, together with other related findings, are given in the remaining parts of this summary.

S7. A survey of seasonal forecasting activities in other parts of the world was conducted in the pilot study. The survey has found that most centres make forecasts of rainfall and temperature. Apart from the Hong Kong Observatory, only two other centres forecast tropical cyclone activity regularly for the western North Pacific or the South China coastal area.

S8. The survey also has revealed that forecasts are made from empirical methods (largely statistical in nature) as well as dynamical methods (namely, dynamical modeling using the equations governing the state and motion of the atmosphere and oceans). That many of the forecasts based on dynamical models are being made on an experimental basis suggests that dynamical modeling in seasonal forecasting has not yet attained a level of performance sufficient for operational use.

S9. Empirical methods have the advantage of being simple to develop and operate. This is the approach used in the pilot study although such methods cannot fully account for the complex nature of the air-sea interaction processes impacting on climate and its variation from year to year. Dynamical models require much more computational resources but have a long-term potential of producing more accurate forecasts because they predict the evolution of climate from physical laws of momentum, energy, etc. As part of the pilot study, a numerical regional climate model was adapted from the Scripps Institution of

Oceanography in the United States with a long-term view of complementing empirical forecasts, and to serve as a vehicle for understanding the response of climate in this part of the world to different climate factors.

S10. For the number of tropical cyclones affecting Hong Kong in the year, ENSO events were found to be statistically significant predictors. The mean number of tropical cyclones affecting Hong Kong in El Niño onset years and the years immediately following El Niño onset is 5.2 and 5.3 respectively, that is, lower than the mean of 6.4 for all years. For La Niña onset years and the years immediately following La Niña onset, the respective means are 7.4 and 7.8. In particular, for all strong El Niño onset years except 1991, and all years immediately following strong El Niño onset except 1983, the number of tropical cyclones affecting Hong Kong is below normal (with “near normal” taken as 6 to 7). Furthermore, all years immediately following strong La Niña onset except 1989 are associated with more than the normal number of tropical cyclones affecting Hong Kong.

S11. The reasons for fewer tropical cyclones to affect the western North Pacific and China in El Niño years especially in the late season (September to November) are an eastward shift in the mean tropical cyclone genesis positions in these years, and a weaker ridge of high pressure over the western North Pacific which steers tropical cyclones more to the northwest than to the west, away from the South China Sea.

S12. For the time of onset of the tropical cyclone season, ENSO and the Quasi-Biennial Oscillation (QBO) were found to be influential. Classifying the time of onset as early (May or earlier), normal (June) and late (July or later), it was found that the onset of the tropical cyclone season in Hong Kong has never been early in El Niño years, and tends to be always late in years when El Niño is followed by La Niña. Onset is never late in La Niña years, and tends always to be early when La Niña coincides with the westerly phase of the QBO. Time of onset is likely to be normal in years when El Niño coincided with the easterly phase of the QBO.

S13. For rainfall (as represented by the rainfall at the Hong Kong Observatory), ENSO and the strength of the winter monsoon in the preceding winter have been identified as statistically significant predictors. Annual rainfall is classified as near normal when it is within half a standard deviation of the long term mean, i.e. between 1958 mm and 2470 mm. Annual rainfall in Hong Kong can be expected to be above normal in years of strong El Niño onset, near normal or above normal in years following El Niño onset irrespective of strength of the El Niño event, and near normal to below normal in years following La Niña onset irrespective of the strength of the La Niña event. In other years, annual rainfall in Hong Kong was found to be inversely related to the strength of the monsoon in the preceding winter.

S14. In May through August of strong El Niño onset years, the wind field in the lower atmosphere has a greater cyclonic tendency, which may be the cause of more rain than usual over the south China coast in these years.

S15. Abundant rain in February to July largely account for the above normal rainfall in the years immediately following El Niño onset. This abundance may be attributed to the presence along the south China coast of stronger than usual southwesterly winds which transport more moisture to the region. In years following La Niña onset, the tendency for below normal rainfall may be attributed to weaker than usual southwesterly winds in June and July over the south China coast, which bring less moisture to the region.

S16. In the summers following winters with weak monsoons, the wind field in the lower atmosphere has a greater cyclonic tendency along the south China coast. This is conducive to enhanced rainfall.

S17. Under the pilot study, experimental forecasts on the number of tropical cyclones expected to affect Hong Kong and the rainfall in Hong Kong in the year were issued in 2001 and 2002. These experimental forecasts were widely covered by the media, demonstrating the public's continued interest for information on the climate of Hong Kong on seasonal time scales. The probability of the forecast being correct was also computed and issued in 2002 to apprise users of the level of confidence associated with the forecast and to enable them to carry out cost-loss analysis as part of their decision making processes.

S18. The performance of the forecasts can be considered as possessing some measure of skill. For 2001, the number of tropical cyclones (near normal) was correctly forecast, though annual rainfall was under-estimated. For 2002, the trend in the number of tropical cyclones affecting Hong Kong (near normal to below normal) was correctly forecast, though not the exact number (5 to 6 versus the actual 3). The annual rainfall in 2002 was 2490.0 mm, close to the upper limit of near normal rainfall (2470 mm) which was forecast.

S19. The forecast made in 2001 of the annual rainfall was based on the consideration of the ENSO factor alone. An additional factor, the strength of the monsoon in the proceeding winter was subsequently identified and used in formulating the 2002 forecast. Had this additional factor been applied in the 2001 forecast, above normal rainfall would have been predicted, making it a correct forecast.

S20. Teleconnection indices, which are indices representing the degree of connection between anomalous atmospheric circulation patterns that appear at the same time in different parts of the world, have been found to be potentially useful as predictors. The annual rainfall in Hong Kong is found to be significantly correlated with the Western Pacific teleconnection index in the preceding October to January. When this index is below normal, Hong Kong is unlikely to see above normal annual rainfall and vice versa. The rainfall in the summer (June to August) in Hong Kong is also found to be significantly correlated with the North Atlantic Oscillation index in the preceding April and May. When this index is below normal, the chance of below normal rainfall in the summer in Hong Kong is low and vice versa. The possible role of teleconnection indices in seasonal forecasting for Hong Kong merits further study.

S21. Preliminary results suggest that the regional climate model adapted from the Scripps Institution of Oceanography has some potential but it has not yet achieved a level of performance sufficient for operational use. Further experimentation should be carried out with a long term goal of providing forecasts of rainfall and temperature several months ahead.

---0---0---0---

1. Introduction

1.1. While weather forecasting deals with the daily development of the weather up to several days ahead, seasonal forecasting is concerned with the average weather condition on time scale of a month to about a year ahead. Seasonal forecasts are also known as long range weather forecasts or short range climate forecasts.

1.2. Because seasonal forecasts give information several months ahead, they can be used by government, business and industry alike to enhance productivity, maximize economic benefit and minimize loss. Specific examples of the applications of seasonal forecasts can be found in ECMWF (1999). A number of climate centres overseas are issuing seasonal forecasts to meet societal needs.

1.3. The Hong Kong Observatory began in the mid-1970s to routinely provide seasonal forecasts of annual rainfall in Hong Kong to the Water Supplies Department for fresh water management purposes. A review can be found in Lau and Chan (1989). These forecasts were stopped in 1998 because of the declining correlation between the predictor used at that time and the annual rainfall.

1.4. Seasonal forecasts are predicated upon the ability to forecast El Niño and La Niña events, collectively known as the El Niño-Southern Oscillation (ENSO) phenomenon, which dominates the variability in climate.

1.5. One of the strongest El Niño events in the 20th century occurred in 1997/1998. Heavy rain fell in June, July and August in 1997 making it the wettest year on record in which 3343 mm of rain fell at the Hong Kong Observatory compared with the normal of 2214 mm. The first tropical cyclone signal was not issued until the last day of July, which was the latest in any year on record up to 1997. Only 2 tropical cyclones affected Hong Kong that year compared with the normal of 6 to 7. The 1997 El Niño persisted into the first half of 1998. No tropical cyclone signal was hoisted until 9 August in 1998, even later than 1997 and the latest date for the first tropical cyclone signal of the year on record. Five tropical cyclones affected Hong Kong that year.

1.6. A La Niña event replaced the El Niño event in the second half of 1998 and it persisted until early 2001. In 1999, tropical cyclone signals were issued for eight tropical cyclones. Five of these eight tropical cyclones necessitated the issuance of the tropical cyclone signal No. 8. Further, four tropical cyclones made landfall over Hong Kong, the first time in the past 50 years when full records of tropical cyclones are available.

1.7. The anomalous climate of 1997, 1998 and 1999 stirred much public interest in the possible connection between the ENSO phenomenon and local climate. The Observatory began to re-examine the possibility of providing seasonal forecasts to the community.

1.8. Given that no two El Niño (and for that matter no two La Niña events) are the same in terms of time of onset, strength and persistence, it is not expected that the impacts on the short term climate of Hong Kong can be easily mapped out. There may also be other climate factors operating at the same time. Mindful of the complexity of the matter, the Hong Kong Observatory nevertheless decided to take up the challenge to satisfy society's needs. It initiated a plan in 2000 to provide a seasonal forecasting service to the community, with the target of completing a pilot study by the end of 2002 to examine the feasibility of making seasonal forecasts.

1.9. During the 1997/1998 El Niño and the ensuing La Niña event, the media and companies in the energy and retail sectors enquired about their connection with climate anomalies in Hong Kong. A question on how much rainfall Hong Kong was expected to receive in 2002 was raised by a member of a District Council during a meeting in May 2002 in the light of the drought then threatening Guangdong. Similar enquiries were received from the Water Supplies Department. There were press enquiries in July 2002 on the late start of the 2002 tropical cyclone season, a request by a utility company in August 2002 for temperature forecasts for the next few months, as well as requests for interviews by the media on the 2002 El Niño and the associated weather in Hong Kong. All point to the need for seasonal forecasts from the community.

1.10. This report outlines the scientific basis for seasonal forecasting, presents a survey on seasonal forecasts issued world-wide, describes the status of the technology, provides an assessment of the predictability of the number of tropical cyclone affecting Hong Kong in a year, the time of onset of the tropical cyclone season and the annual rainfall in Hong Kong, describes the techniques developed for forecasting them, presents an evaluation of the experimental seasonal forecasts in 2001 and 2002, and proposes the way forward.

2. Objective, Scope and Approach of the Pilot Study

2.1. Objective

2.1.1. The objective of the pilot study is to examine the feasibility of making seasonal forecasts for Hong Kong.

2.2. Scope of the Pilot Study

2.2.1. The focus of the pilot study is the prediction of the number of tropical cyclones affecting Hong Kong within the year and the annual rainfall in Hong Kong. These are the two parameters in which the community has expressed the most interest as their abundance or deficit affects closely the safety and well-being of the society.

2.2.2. Related to the number of tropical cyclones affecting Hong Kong in a year is the time of onset of the tropical cyclone season in Hong Kong. The predictability of the onset time is also examined.

2.3. Approach

2.3.1. The approach used in the pilot study is:

i). Identification of climate factors impacting on the number of tropical cyclones affecting Hong Kong in a year, the time of onset of the tropical cyclone season and the annual rainfall.

ii). Development of conceptual models and empirical schemes for forecasting these variables.

iii). Issuing experimental seasonal forecasts on the number of tropical cyclones affecting Hong Kong in a year and the annual rainfall in Hong Kong.

iv). Verification of these experimental forecasts.

v). Adaptation of a regional climate model to downscale global climate forecasts to southern China.

vi). Proposing the way forward based on the experience gained during the pilot study.

2.3.2. The work done according to the above approach is reported in the remainder of this report. In the course of the pilot study, actions were taken to build capacity within the Hong Kong Observatory for seasonal forecasting. In this regard, Professor Ding Yihui, former Director of the National Climate Centre, China Meteorological Administration, and Co-chairman of Working Group I of the Intergovernmental Panel on Climate Change, was invited to lecture on seasonal forecasting at the Hong Kong Observatory in May 2001.

2.3.3. Monthly meetings were held at the Hong Kong Observatory among those involved in seasonal forecasting work to report progress, present findings, share knowledge, and discuss issues and the way forward.

2.3.4. Meteorological investigations carried out in the context of the pilot study have resulted in a number of technical papers, listed below, being presented at international conferences/workshops or published:

i). Chang, W. L., and M. C. Wu, 2001: Low frequency oscillations during Hong Kong's rainy season in 1998. Scientific Conference on the South China Sea Monsoon Experiment (SCSMEX), 17-20 April, 2001, Shanghai, China. Reprint No. 430, Hong Kong Observatory.

ii). Chang, W. L., 2001: Implementation of a regional climate model at the Hong Kong Observatory. *Research Activities in Atmospheric and Oceanic Modelling*, H. Ritchie (Editor). Report No. 31, CAS/JSC Working Group on Numerical Experimentation, WMO/TD No. 1064, World Meteorological Organization, Geneva, Switzerland.

iii). Hui, T. W., K. H. Yeung, and W. L. Chang, 2001: Adaptation of NCEP RSM model for seasonal forecasting. Third RSM International Conference, Taipei, 23-27 July 2001. Reprint No. 436, Hong Kong Observatory.

iv). Hui, T. W., W. L. Chang, and Karen K. Y. Shum, 2002: Seasonal forecasting for Hong Kong with ensembles from a regional model – some preliminary results. 2nd APCN Working Group Meeting, 11-13 June, 2002, Seoul, Republic of Korea. Reprint No.480, Hong Kong Observatory.

v). Leung, Y. K., and W. M. Leung, 2002: Effect of ENSO on the number of tropical cyclones affecting Hong Kong. Workshop on the Network System for Monitoring and Predicting ENSO Event and Sea Temperature Structure of the Warm Pool in the Western Pacific Ocean, Macau, China, 5-7 February 2002. Reprint No. 453, Hong Kong Observatory.

vi). Wu, Man-Chi, 2002: Prediction of rainfall during the dry season in Hong Kong. Fourth Workshop on Regional Climate Prediction and Applications for Tropical Pacific Islands and Rim. University of Oklahoma, Norman, Oklahoma, 27 May to 5 July 2002. (*Paper being reviewed by the Workshop's external referees*).

vii). Wu, M. C., W. L. Chang, and W. M. Leung, 2002: Impact of El Niño-Southern Oscillation (ENSO) events on tropical cyclone landfalling activity in the western North Pacific. Sixth Joint Meeting of Prediction of the East Asian Summer Monsoon, 16-18 May 2002, Beijing, China. Hong Kong Observatory. (*Paper submitted to Journal of Climate).*

viii). Kung, Terence (**龔穎恆**)[1], and Joly Ho (**何嘉玲**), 2002: A conceptual model for forecasting the onset of the tropical cyclone season in Hong Kong. 16th Guangdong - Hong Kong - Macau Seminar on Meteorological Science and Technology, 30-31 January 2002, Guangzhou. Reprint No. 460, Hong Kong Observatory. (Original in Chinese).

2.3.5. A webpage was developed on the Hong Kong Observatory intranet to serve as a climatological database as well as a portal to sites on ENSO and seasonal forecasts issued by other centres. The purpose is to facilitate the monitoring of the status of the ENSO and global/regional climate as well as access to forecasts issued by other centres. Useful references, educational resources, data summaries and graphics are also incorporated in the webpage to allow convenient recovery of information for research and answering enquiries. The webpage is linked to statistical tools available on the internet and provides a convenient platform for performing simple statistical analysis such as significance testing, the computation of contingency tables, etc.

---

[1] Throughout the text, in referring to publications which are originally in Chinese, the name(s) of the author(s) in the original language will be shown next to the translated name(s). These publications are also numbered in the order of their appearance in the text.

3. Scientific Basis for Seasonal Forecasts

3.1. Forecasts of the day to day evolution of the weather are predicated on the initial state of the atmosphere. As errors in initial conditions due to imperfect and incomplete observations grow rapidly when projected forward in time, there is a fundamental limit of about two weeks beyond which detailed forecasts are no longer possible.

3.2. Seasonal forecasts, on the other hand, are predicated on the changing conditions of the earth's surface such as changes in sea surface temperature (SST) and in snow, ice and vegetation cover. The time scales of these changes are long, from weeks to months to years, and so have little influence on day to day weather variations. They do however influence the average weather condition of comparable or longer periods. This is the basis for predictability of the mean weather condition a month to a year ahead (Goddard *et al.* 2001, Stone 2001). A detailed discussion of the differences between weather and seasonal forecasting can be found in the WMO Statement on the Scientific Basis for, and Limitations of Weather and Climate Forecasting (WMO 2002).

3.3. Seasonal forecasts are therefore couched in terms of mean values over the next few months or year, instead of day to day changes in temperature or rainfall. Furthermore, because the surface conditions change only the probability of a particular climate pattern appearing (Webster and Palmer 1997, Goddard *et al.* 2001, WMO 2002), seasonal forecasts are often couched in probabilistic terms.

3.4. El Niño events are associated with positive SST changes or warming in the equatorial eastern and central Pacific. La Niña events are associated with negative SST changes or cooling in the equatorial eastern and central Pacific. Such warming or cooling occurs every December off the coasts of Chile and Ecuador in South America, and normally lasts a few months. Now the names El Niño and La Niña are reserved for extensive and persistent SST changes extending from the coasts of Chile and Ecuador westwards all the way to the International Dateline, and lasting a year or more. SSTs in four areas in the equatorial eastern and central Pacific denoted Niño 1, Niño 2, Niño 3 and Niño 4 (Fig. 3.1), are commonly used as indices for denoting the strengths of the El Niño or La Niña events.

3.5. El Niño and La Niña events are also called respectively warm and cold ENSO (El Niño Southern Oscillation) events. This is because closely linked to the warming or cooling of the equatorial central and eastern Pacific Ocean is an oscillation in atmospheric pressure called the Southern Oscillation. It is represented by the Southern Oscillation Index (SOI) which is negative in El

Niño events and positive in La Niña events. The SOI index is given by the difference between the sea level pressure anomaly at Tahiti and Darwin (Tahiti minus Darwin).

3.6. Of the factors affecting climate variability, apart from the annual cycle, ENSO accounts for the major proportion of the variability on seasonal to decadal time scales (Wright 1985). A few paragraphs will therefore be devoted here to summarize ENSO's essential features. Detailed information on ENSO and its global impacts can be found on a number of websites including http://www.pmel.noaa.gov/tao/elnino/nino-home.html and http://www.elnino.noaa.gov/ of the United States National Oceanic and Atmospheric Administration (NOAA), http://iri.columbia.edu/climate/ENSO/background/ of the International Research Institute for Climate Prediction (IRI), and in a number of books [Philander 1990, Glantz *et. al.* 1991, Allan *et al.* 1996, Chao (**巢紀平**) 1993[1] and others].

3.7. ENSO events, in the form of the large scale and persistent warming or cooling of the equatorial central and eastern Pacific, occur roughly once every three to four years (Brigg 1990). The interval between events can be as short as 2 years, or as long as 7 years (Neelin *et al.* 2000) to 10 years (Brigg 1990). El Niño events usually start to develop in mid-May, and attain maturity the following winter (WMO 1999). This linkage with the annual cycle is referred to as phase locking, details of which can be found in Neelin *et al.* (2000). Once triggered, an El Niño event usually persists for 12 to 18 months. In about 30% of the cases an El Niño event is followed by a La Niña event. A La Niña event usually last for 12 to 18 months but can also be longer than 2 years such as in the 1998-2001 case.

3.8. Several theories have been advanced for what excites or triggers ENSO events. Amongst them are the winter monsoon [Li (**李崇銀**) *et al.* 1988[2]], equatorial Kelvin waves and 30-60 day atmospheric oscillations known as Madden-Julian Oscillations (WMO 1999, Zhang and Gottschalk 2002). It is noted that Madden Julian Oscillations also have other impact on intraseasonal climate variability, and their propagation through Hong Kong has been studied by and Leung and Wu (2000) and Chang and Wu (2001).

3.9. The frequency of occurrence of ENSO events is not stationary. An and Wang (2000) found that the interval between events increased from 2-4 years during 1962-1975 to 4-8 years during 1980-1993. From the results of a wavelet analysis shown in Fig. 3.2 it would appear that there is a tendency for the interval to revert back to the 2-4 year mode from the mid-1990s. There is also the suggestion that there have been more ENSO events than La Niña events since the 1970s. The occurrence of several weak to moderate El Niño events during 1990-1995 without intervening La Niña events is statistically very rare. It is not yet clear whether the change in ENSO variability is associated with global warming (Trenberth and Hoar 1996, WMO 1999, IPCC 2001).

3.10. Although ENSO events take place in the equatorial central and eastern Pacific, its influence on the climate is global (Ropelewski and Halpert 1987). The losses they inflict worldwide are considerable (see WMO 1999 for an account of the damages inflicted by the 1997/1998 El Niño). ENSO causes the position of the ascending and rain bearing branch of the Walker circulation to be shifted. In turn, global circulation and climate patterns are altered and ENSO thereby teleconnects its influence on the weather and climate to various parts of the world (see Glantz *et al.* 1991 for details).

3.11. The response of climate to ENSO varies. This is because not all ENSO events are the same in terms of time of onset, strength, persistence, etc. (WMO 1999). The presence of other ENSO-like oscillations in the atmosphere such as the 20-30 year Pacific Decadal Oscillation (PDO) described by Mantua *et al.* (1997) also modulates climate's response. How these oscillations can be used to predict climate variability is still a matter of investigation by the meteorological community. This is one of the difficulties in seasonal forecasting yet to be overcome.

3.12. The effect of ENSO on tropical cyclone activity in the western North Pacific has gained wide attention. It has been examined by Gray (1993), Lander (1994), Chan (2000) and Wang and Chan (2002) among others. The use of ENSO as a predictor of tropical cyclone activity in the western North Pacific has been attempted by Chan *et. al.* (1998, 2001) as well as by Rockett and Saunders (2002), and by Gray *et al.* (2002) for the Atlantic basin.

3.13. The impacts of ENSO events on climate variability in China have been documented in the English literature by investigators such as Bao and Xiang (1993), Ding (1994), Tian (1999), Liu and Li (1999) and others, and in the Chinese literature by Chen (**陳菊英**) (1991)[3], Liu (**劉永強**) and Ding (**丁一匯**) (1995)[4], National Climate Centre (**中國氣象局國家氣候中心**) (1998)[5], Zhao (**趙振國**) (1996)[6a], Zhao (**趙振國**) (1999)[6b], Zhao (**趙振國**) *et al.* (2000)[7] and others.

3.14. ENSO's effects on climate variability in Hong Kong have been studied by Lam (1993), Au (**區展衡**) and Chang (**張文瀾**) (1998)[8], Chang (1999), Leung and Leung (2002), Wu (2002), and Kung (**龔穎恆**) and Ho (**何嘉玲**) (2002)[9]. For Macau, ENSO's impacts have been documented by Lou *et al.* (2002).

3.15. The increasing amount of observations on and a better understanding of the ENSO phenomenon together with the increasing power of computers have led to increasingly accurate prediction of ENSO events (Stone 2001). Some major centres providing ENSO information and outlooks on the internet are the National Climate Centre of the China Meteorological Administration at http://ncc.cma.gov.cn/apn/predictions.htm, the Tokyo Climate Centre of the Japan Meteorological Agency at http://okdk.kishou.go.jp/products/elnino/outlook.html, the International Research Institute for Climate Prediction at http://iri.columbia.edu/climate/ENSO/currentinfo/update.html, NOAA's Climate Prediction Centre at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/ensoforecast.html, and Australia's Bureau of Meteorology at http://www.bom.gov.au/climate/enso/. ENSO prediction models have been described by Barnston *et al.* (1999), Zhao (**趙其庚**) (1999)[10] and Zhao (**趙宗慈**) *et al.* (2000)[11] among others.

3.16. The increased ability to predict SSTs and ENSO evolution has paved the way for predicting the resulting climate anomalies. Evidence of the predictability of climate anomalies on seasonal time scales based on SSTs changes has been demonstrated by Palmer and Anderson (1994), Shukla (1998) and others.

3.17. Many meteorological agencies and institutions have begun to provide climate forecasts either to their own community and/or to the international community (see Section 4.2). In particular, the International Research Institute for Climate Prediction (IRI) was set up by the National Oceanic and Atmospheric Administration (NOAA) of the United States to foster the production and use of global forecasts of seasonal to interannual climate variability for the benefit of society (WMO 1999).

4. Current Status of the Technology and Survey of Seasonal Forecasting Activities

4.1 Current Status of the Technology

4.1.1. Empirical methods in the form of statistical or analogue models have a long history in seasonal forecasting. Statistical methods try to build relationships between predictor(s) and predictand(s). Sir Gilbert Walker used them in the first part of the 20th century to forecast the Indian monsoon rainfall (Allan *et al.* 1996). Analogue methods try to find matches between past cases and the current case, assuming that if the initial conditions are alike, the climate pattern would evolve in much a similar way. The techniques employed by the Hong Kong Observatory in formulating seasonal forecasts so far (Bell 1976, Hui and Chang 2000) fall into the category of empirical models.

4.1.2. Empirical models are easy to operate, requiring relatively little computational resources. The major disadvantage is that they attempt to predict complex non-linear atmosphere-ocean processes by linear relationships.

4.1.3. The other approach to seasonal forecasting which is more recent is dynamical modeling. Dynamical models try to predict the complex atmosphere-ocean processes using the non-linear equations of mass conservation, motion, energy etc. They require tremendous computer resources to operate, but can better simulate the physical processes and therefore have the potential to produce more accurate forecasts. The rapidly increasing power and falling costs of computers have resulted in a growing popularity in the use of dynamic models. The reader is referred to Gates *et. al.* (1999) for a summary of these global atmospheric models and their performance, Li (**李維京**) (2000)[12] and Dong (**董敏**) *et. al.* (2000)[13] for an overview of the dynamical models used by NCC, and to Wang *et. al.* (2001) on the dynamical models used by the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences.

4.1.4. Other advantages of dynamical models are that they allow physical understanding of the climate processes to be gained (Anderson *et al.* 1999), and can be integrated repeatedly using slightly different initial conditions to give an ‘ensemble’ of forecasts either from a single model as described in Dalcher *et al.* (1988) or a ‘superensemble’ from a number of different models as described in Krishnamurti *et. al.* (1999). These ensembles or superensembles allow the probabilities of different climate states occurring to be inferred. A good dynamical model should therefore be the best tool for predicting on seasonal time scales (Trenberth 1997).

4.1.5. Presently the forecast skill of empirical models is comparable to dynamical models (Shukla *et al.* 2000, Wang and Zhu 2001). The skills of both are higher for the tropics, where the teleconnection signals are stronger, than in the extra-tropics where climate variability is greater (Glantz 1998, Anderson *et al.* 1999).

4.1.6. The skill of seasonal forecasts based on empirical methods depends to a large extent on ENSO events being successfully forecast. Presently, the level of skill of ENSO forecasts made by major centres is better than even, at about 0.6 (Barnston *et al.* 1999).

4.2. Survey of Seasonal Forecasting Activities

4.2.1. A survey of seasonal forecasts issued publicly by meteorological agencies and institutions around the world has been conducted to see what are the most commonly predicted parameters and the forecasting methods used. It does not cover forecasts which are only circulated internally as information on these is not generally available. The survey is based on information available on the internet and in the World Meteorological Organization' s annual reports on seasonal forecasting (see for example, WMO 1999). The most significant activities are summarized below.

4.2.2. *Australia*

The Bureau of Meteorology (BoM) issues seasonal forecasts of the probabilities of temperature and precipitation being above or below the median in the coming three months. These forecasts are based on the statistical analysis of past data and updated every month. Seasonal outlooks on tropical cyclone activity for Northwest and North Australia based on statistical methods are also provided.

4.2.3. *China*

The National Climate Centre (NCC) of the China Meteorological Administration (CMA) issues monthly forecasts of temperature and rainfall anomalies. These forecasts are based on dynamical modelling.

4.2.4. *European Centre for Medium Range Forecasting*

The European Centre for Medium Range Forecasting (ECMWF) uses coupled ocean-atmosphere circulation models to produce forecasts of mean surface temperature anomalies, mean rainfall and mean sea level pressure anomalies, as well as the probabilities of the these three parameters exceeding their respective ensemble medians. The forecasts are issued on an experimental basis.

4.2.5. *Hong Kong, China*

4.2.5.1. As noted in the Introduction, the Hong Kong Observatory issues in March experimental forecasts of the annual rainfall and the annual number of tropical cyclones affecting Hong Kong. Statistical and analogue methods are used in formulating these forecasts.

4.2.5.2. The Department of Physics and Materials Science at the City University of Hong Kong issues in April/May outlooks on the number of tropical cyclones occurring in the western North Pacific, the South China Sea and making landfall along the south China coast between Hainan and Xiamen during the year. Updates are provided in June. Statistical methods are used to formulate the forecasts.

4.2.6. *Japan*

Using an atmospheric global circulation model, the Tokyo Climate Centre of the Japan Meteorological Agency (JMA) issues climate forecasts up to 28 days ahead. The elements forecast are mean sea level pressure, 500 hPa geopotential heights and 850 hPa temperatures. These forecasts are updated every week. Three-monthly outlooks will be provided from 2003.

4.2.7. *South Korea*

4.2.7.1. The Korean Meteorological Administration (KMA) issues forecasts of rainfall, 850 hPa temperature, sea level pressure, 500 hPa and 200 hPa height and temperature up to three months ahead for the East Asian region. The forecasts are generated by an atmospheric global circulation model.

4.2.7.2. KMA through the Asia Pacific Economic Co-operation (APEC) Climate Network (APCN) project is also planning to produce multi-model superensemble forecasts including rainfall and temperature up to 3 months ahead. An overview of APCN project can be found on http://www.apcn21.net.

4.2.8. *UK*

4.2.8.1. The UK Meteorological Office uses an atmospheric general circulation model to produce probability forecasts of rainfall and temperature anomalies exceeding the ensemble means. These forecasts are issued on an experimental basis.

4.2.8.2. The Benfield Greig Hazard Research Centre of the University College London through its Tropical Storm Risk website issues in March or April outlooks on tropical cyclone activity in the western North Pacific, Atlantic and Australian regions. Forecasts of the number of tropical cyclones landfalling in Japan are also issued. The forecasts are based on regression methods.

4.2.9. ***United States***

4.2.9.1. The Climate Prediction Centre (CPC) of the National Oceanic and Atmospheric Administration (NOAA) gives probabilistic outlooks on seasonal temperature and rainfall for the United States up to 12 months ahead. These outlooks are based on a combination of a coupled ocean-atmosphere model, optimal climate normals and canonical correlation analysis.

4.2.9.2. The Department of Atmospheric Science, Colorado State University, issues outlooks on the number of tropical cyclones likely to affect the Atlantic basin during the year. The outlooks are based on a combination of analogue and statistical techniques. Updates are provided frequently.

4.2.9.3. The International Research Institute for Climate Prediction (IRI) issues on an experimental basis probabilistic seasonal outlooks of precipitation and temperature for the entire globe. These forecasts are based on a combination of an atmospheric global circulation model and canonical correlation analysis.

4.2.9.4. The Seasonal to Interannual Prediction Project (NSIPP) of the National Aeronautics and Space Administration (NASA) issues on an experimental basis forecasts of global rainfall and temperature anomalies up to 3 months ahead. The forecasts are based on a coupled atmosphere-ocean model.

4.2.9.5. The Experimental Climate Prediction Centre (ECPC) of the Scripps Institution of Oceanography issues on an experimental basis forecasts of temperature and precipitation anomalies for different regions of the world up to 12 weeks ahead. These forecasts are based on an atmospheric global circulation model.

4.2.10. ***Summary***

4.2.10.1.The above survey shows that almost all centres which issue seasonal forecasts issue rainfall and temperature forecasts, two of the variables generally regarded as of most concern to society (Goddard *et al.* 2001). Apart from the Hong Kong Observatory, two other centres forecast tropical cyclone activity regularly for the western North Pacific and the south China coastal areas.

4.2.10.2. The forecasting methods used include empirical, dynamical as well as hybrid statistical/dynamical models. Empirical models are mostly in the form of analogues, linear regression including multivariate regression and canonical correlation analysis. Dynamical models include separate atmospheric global circulation models and ocean global circulation models and coupled atmosphere-ocean circulation models.

4.2.10.3. Some centres formulate their forecasts in deterministic terms, some in probabilistic terms and some give both. Deterministic forecasts are expressed as forecast values or forecast anomalies (forecast value minus the long term observed mean/median or ensemble mean/median value). Probability forecasts are expressed as the chance of the parameter forecast being above, near and below the long term mean/median, or the ensemble mean/median. Probability forecasts enable users to carry out cost-loss analysis during decision making processes to determine, for example, the possible gain by taking action to hedge against climate related risks versus not taking action. Two examples of cost-loss analysis are shown in Annex 1. Further details on cost-loss analysis can be found in Winkler and Murphy (1985).

4.2.10.4. Many of the forecasts especially those based on dynamical modeling are being made on an experimental basis (e.g., ECMWF, UK Meteorological Office, IRI). This suggests that dynamical modeling has not yet attained a level of performance sufficient for operational use.

4.3. Approach Taken by the Hong Kong Observatory

4.3.1. Empirical models will continue to be useful for seasonal forecasting, especially for forecasting tropical cyclone activity which cannot yet be simulated with skill by dynamical models. They have been and will continue to be the Hong Kong Observatory’ s primary tool in seasonal forecasting.

4.3.2. In view of the potential of dynamical models, the Hong Kong Observatory has adapted a regional climate model for experimentation in seasonal forecasting with a long-term view of complementing empirical forecasts and as a tool for studying the response of climate in this part of the world to the forcing of different climate factors. This model and its adaptation are described in Section 10.

5. Predictability of the Number of Tropical Cyclones Affecting Hong Kong in a Year

5.1. Background

5.1.1. The number of tropical cyclone affecting Hong Kong is determined as the number of tropical cyclones necessitating the issuance of local tropical cyclone warning signals. This definition carries a degree of subjectivity on the part of the forecaster. Although objective criteria can be used to define this number, and indeed this has been examined, the prevailing definition reflects better the concern of the public.

5.1.2. The main factors bearing on climate variability in China have been found to be ENSO, the subtropical high over the western North Pacific, the East Asian monsoon, the extent of snow cover on the Tibetan Plateau, and the East Asian blocking high [Ding (**丁一匯**) 2001[14], National Climate Centre (**中國氣象局國家氣候中心**) 1998[5]].

5.1.3. For tropical cyclones, on average, the number of tropical cyclones making landfall over China is less in El Niño years and more in La Niña years [Ding 1994, Tian 1999, National Climate Centre (**中國氣象局國家氣候中心**) 1998[5]]. For Guangdong, Shi (**施能**) and Zhou (**周家德**) (1989)[15] found that fewer tropical cyclones are likely to make landfall in El Niño years, and more in La Niña years. Liu (**劉春霞**) (2000a,b)[16,17] showed that for El Niño (La Niña) events attaining maturity in spring, the tendency is for fewer (more) tropical cyclone to make landfall over Guangdong during the year. Wu (**吳尚森**) *et al.* (2000)[18] also showed that for Guangdong there tended to be fewer landfalls in El Niño years, and more in La Niña years although it is not always the case. ENSO, for which forecasts by major centres are available on the internet, is therefore a potential predictor for the number of tropical cyclones affecting Hong Kong in a year.

5.1.4. The motion of tropical cyclones is greatly influenced by the strength and position of the subtropical high [Chen (**陳聯壽**) and Ding (**丁一匯**) 1979[19]]. However, forecasts of the subtropical high are not available on the internet to allow this factor to be used explicitly in formulating forecasts of tropical cyclone activity. Fu and Teng (1993) as well as others have shown that the strength and position of the subtropical high are closely related to ENSO. Thus, the effect of the subtropical high on tropical cyclones activity is covered to a large extent by that of ENSO.

5.1.5. Prediction of the annual number of tropical cyclone landfalls on Guangdong province has been attempted by Liu (**劉春霞**) (2000c)[20] using equatorial eastern Pacific SST as a predictor, and by Xie (**謝定升**) *et al.* (2000)[21] using SST over the western North Pacific as a predictor. According to literature surveyed, snow cover, blocking high and the strength of the monsoon have not been used for forecasting tropical cyclone activity. They are more relevant to rainfall and these factors will be considered in Section 7.

5.1.6. The Quasi-Biennial Oscillation (QBO), which is the change of the wind direction in the stratosphere between 20 and 24 km high over the tropics from east to west and from west to east every two to two and a half years, has been found to be a factor affecting tropical cyclone activity over the Pacific and Atlantic basins. Background information on the QBO can be found in Bell (1974), Lau (1992) and also on the internet at http://dss.ucar.edu/cdroms/karin_labitzke_strat_grids/html/main.html.

5.1.7. Gray (1993) has found that the *western* part of the western North Pacific can expect a small decrease in tropical cyclone activity during the westerly phase of the QBO, and a small increase in the easterly phase. On the other hand, the *eastern* part the western North Pacific can expect a small increase in tropical cyclone activity during the westerly phase, and a small decrease in the easterly phase. Chan (1995), however, finds an increase in tropical cyclone activity over the western North Pacific during the westerly phase. Further, Chan (1995) notes that during and shortly before or after ENSO years, the QBO-tropical cyclone activity relationship does not hold very well which suggests that ENSO is a stronger modulator. QBO is therefore another potential predictor, after ENSO, for the number of tropical cyclones affecting Hong Kong in a year.

5.2. Forecasting for Hong Kong

5.2.1. Spectral analysis applied to the number of tropical cyclones affecting Hong Kong between 1946-2001 shows that the main periodicities in the data are about 3.5 years and 7 years (Fig. 5.1). These periodicities correspond to those of ENSO, and the 7-year cycle might also be a harmonic of the 3.5-year periodicity. They are compatible with the 3- and 7-year periodicities found by Liu (**劉春霞**) (2000d)[22] and the 3- and 8-year periodicities found by Xie (**謝炯光**) and Ji (**紀忠平**) (2000)[23] for tropical cyclones landfalling in Guangdong or coming within 1 degree latitude of the coast of Guangdong.

5.2.2. Chang (1999) and Leung and Leung (2002) have examined the impact of ENSO on the number of tropical cyclones affecting Hong Kong in a year.

In El Niño onset years and the years immediately following El Niño onset these numbers are respectively 5.2 and 5.3, which are below normal. Here near normal is defined as the 1961-1990 long-term mean of 6.43 plus/minus half a standard deviation of 0.96 (i.e. between 5.5 and 7.4, and taken to be between 6 and 7 when whole numbers are used).

5.2.3. For La Niña years and the years immediately following La Niña onset, the respective means are 7.4 and 7.8, which are above normal. These tendencies are similar to those for Guangdong as reported by Liu (**劉春霞**) (2000a, b)[16,17] and Wu (**吳尚森**) *et al.* (2000) [18]. The statistics are shown in Table 5.1.

5.2.4. In particular, it can be seen from Table 5.1 that for all *strong* El Niño onset years except 1991, and all years following strong El Niño onset except 1983, the number of tropical cyclones affecting Hong Kong is below normal. Further, all years following *strong* La Niña onset except 1989 are associated with more than the normal number of tropical cyclones affecting Hong Kong.

5.2.5. That Hong Kong is affected by fewer tropical cyclones in El Niño years compared to La Niña years is well illustrated in the late season (September to November) tropical cyclone track densities shown in Fig. 5.2a and Fig. 5.2b. This is due in part to a eastward shift in the mean tropical cyclone genesis positions in El Niño years, and to a weaker subtropical ridge over the western North Pacific which steers tropical cyclones more to the northwest than to the west away from the South China Sea. Details on these can be found in Wu and Lau (1992), Lander (1994), Chan (2000), Wu *et al.* (2002).

5.2.6. No major 2-year spectral peak is evident in Fig. 5.1. This to some extent confirms that the modulating effect of QBO is small compared with ENSO. Nevertheless, analysis of past records shows that the easterly phase is very unlikely to see an above normal number of tropical cyclones affecting Hong Kong (1/17 chance). The probabilities during the westerly phase is less biased, with the highest probability (6/13) associated with above normal number of tropical cyclones affecting Hong Kong (Table 5.2). This is consistent with Chan's (1995) finding for the westerly phase.

5.2.7. Table 5.1 and Table 5.2 have been used in March 2002 to formulate the forecast of the number of tropical cyclones affecting Hong Kong during the year, on the basis of the onset of a weak El Niño being expected and the QBO entering a westerly phase.

5.2.8. It should be recalled that the number of tropical cyclones affecting Hong Kong is defined as the number of tropical cyclones necessitating the issuance of local tropical cyclone signals. Although this is in line with the public's interest, it entails a degree of subjectivity on the part of the forecaster. The use of the number of tropical cyclones entering the 500 km radius as an alternative indicator of the number of tropical cyclones affecting Hong Kong has been studied during the formulation of the 2002 experimental forecast. This choice is deemed reasonable as the long-term mean for the number of tropical cyclones entering this radius is 6.4, same as the long-term mean for the annual number necessitating the issuance of local tropical cyclone warning signals affecting Hong Kong (Table 5.3).

5.2.9. The 3-year and 7-year periodicities are again evident in the results of the spectral analysis of the annual number of tropical cyclones entering within 500 km of Hong Kong (Fig. 5.3), and suggest that the 500 km radius data series is to a large extent representative of the data series of tropical cyclones affecting Hong Kong.

5.3. Framing of the Forecasts

5.3.1. In formulating the experimental forecast for 2002, the original forecast for the number of tropical cyclones expected to affect Hong Kong was 4 to 6 spanning three whole numbers. Following a discussion within the department in March 2002, it was decided that tropical cyclone forecasts should be given a range of two consecutive digits, e.g., 4 to 5, 5 to 6, instead of spanning three digits so that the spread would not be too wide from the public's point of view (see Section 8 for details). On that basis, the forecast issued near the end of March 2002 was for 5 to 6 tropical cyclones affecting Hong Kong during the year. The probability of the forecast being correct was also estimated and issued. The way the 2002 experimental forecast was presented was well received by the public and could be used in the future.

6. Predictability of the Time of Onset of the Tropical Cyclone Season in Hong Kong

6.1. Background

6.1.1. Besides the number of tropical cyclones likely to affect Hong Kong, when during the year the first tropical cyclone would affect Hong Kong (in terms of issuance of local tropical cyclone signals) is also something the public likes to know. This has come out by enquiries received in the middle of 2002 concerning the late start of the 2002 tropical cyclone season.

6.1.2. There is no previous study on the time of onset of the tropical cyclone season in Hong Kong. For Guangdong, Xie (**謝炯光**) (2000)[24] finds that the onset of the tropical cyclone season tends to be late in El Niño years, and early in La Niña years. That this might also be case for Hong Kong is suggested by the late start of the tropical cyclone season in 1997, 1998 and some other El Niño years.

6.2. Forecasting for Hong Kong

6.2.1. Based on the distribution of the months between 1961 and 2000 in which Hong Kong was first affected by tropical cyclones (Fig. 6.1), Kung (**龔穎恆**) and Ho (**何嘉玲**) (2002)[9] classified the onset of the tropical cyclone season in Hong Kong as early if the first tropical cyclone to affect Hong Kong occurred in or before May, normal if in June, and late if in July or later. The frequencies of occurrence of early, normal and late onsets are 27.5%, 40% and 32.5% respectively. It is possible to shift the dividing dates by several days to make the percentages equal, but this would make it more difficult for the public to remember. Dividing by whole months is considered more acceptable.

6.2.2. Kung(**龔穎恆**) and Ho (**何嘉玲**) (2002)[9] compiled statistics on early, normal and late onset associated with different ENSO and QBO phases (Table 6.1 to Table 6.3), and noted that:

i). Irrespective of the phase of the QBO, the onset of the tropical cyclone season in Hong Kong has never been early in El Niño years, and never been late in La Niña years.

ii). In years when La Niña coincides with the westerly phase of the QBO, onset tends to be early.

iii). In years when El Niño changes into La Niña, onset tends to be late irrespective of the phase of the QBO.

iv). In years when El Niño coincided with the easterly phase of the QBO, onset is likely to be normal.

These observations together with Table 6.1 to Table 6.3 enable forecasts of the time of onset of the tropical cyclone season to be made.

6.3. Framing of the Forecasts

6.3.1. The forecasts should be framed as the tropical cyclone season starting “early, before June”, “in June, near normal”, and “late, after June”, which should be easily understood by the public.

7. Predictability of Annual Rainfall in Hong Kong

7.1. Background

7.1.1. Bell (1976) was the first to advocate the possibility of seasonal forecasts of rainfall in Hong Kong. He discovered that the strength of the monsoon in the preceding winter was inversely related to the summer rainfall in Hong Kong (as represented by the rainfall at the Hong Kong Observatory), and he used the mean January pressure difference between Tokyo in Japan and Irkutsk in Russia to represent the strength of the winter monsoon. However, correlation between this pressure difference and summer rainfall deteriorated since the late 1980s and forecasts in the series were stopped in 1998.

7.1.2. The development of El Niño in the form of the difference between the mean SST in December-January-February and that in the preceding September-October-November at Canton Island had also been used a predictor. But the correlation was not statistically significant (Lau and Chan 1989). This can now be understood in terms of the phase locking nature of ENSO. The value of a predictor before April are unlikely to capture the development and impacts of El Niño events.

7.1.3. The exceptionally heavy rain in 1997 coincided with the onset of one of the strongest El Niño events in the 20th century, and the relationship between rainfall and ENSO in Hong Kong was re-examined as part of the pilot study.

7.1.4. The relationship between rainfall in the rainy season in China and ENSO is a still a controversial issue (Wang *et. al.* 2000). Despite El Niño's influence in the disastrous flooding of the Yangtze River Valley in the summer of 1998 (Huang *et. al.* 2000), NOAA's schematic of the global impacts of El Niño does not regard El Niño as having a consistent impact on summer rainfall in China (Fig. 7.1).

7.1.5. Shen and Lau (1995) have found that that there is a prominent biennial signal in the East Asian summer monsoon rainfall over southeast China. Lau and Weng (2001) suggest that during the 1997-1998 ENSO event, although the flood in southern China in the summer of 1997 was mainly associated with the growing phase of the El Niño, rainfall variability over southern China during this event is chaotic with no clear dominance of El Niño or biennial signals.

7.1.6. The biennial signal here refers to oscillations in the troposphere and is distinct from the QBO in paragraphs 5.1.6 and 5.1.7 which is a stratospheric phenomenon. In this Tropospheric Biennial Oscillation (TBO), the summer monsoon in China will be strong following El Niño-like conditions in the previous winter, and weak following La Niña-like conditions in the preceding winter (Chang *et al.*, 2000). Details on the TBO in general can be found in Chang and Li (2000), Li *et al.* (2001) and Meehl and Arblaster (2002).

7.1.7. For southeast China and Guangdong, Zhang *et al.* (1999) and Zhang (**張人禾**) (2000)[25] suggest that in El Niño summers an anticyclone brings subsidence to southeastern China and consequently less rainfall. On the other hand, Xu (**許麗章**) (1994)[26] finds that for Guangdong as a whole, the effect of El Niño on summer rainfall is not evident. For the city of Guangzhou, Liang (**梁暖培**) and Liang (**梁必騏**) (1995)[27] find that in moderate and strong El Niños, rainfall tends to be above normal. For weak El Niños, rainfall tends to be below normal. For Macau, Lou *et al.* (2002) find that annual rainfall tends to be higher in El Niño and La Niña years than in normal years.

7.2. Forecasting for Hong Kong

7.2.1. Of the five climatic factors affecting climate variability in China mentioned in Section 5.1.2, Ji (**季勁鈞**) (1990)[28] has shown that the correlation between the anomaly of the winter snow cover over the Tibetan Plateau and the anomaly of the summer rainfall is highest over Nan Ling. But the correlation over the south China coastal areas is not given. Peng (**彭公炳**) *et al.* (1992)[29] as well as Chen (**陳興芳**) and Zhao (**趙振國**) (2000)[30] suggest that if the winter snow cover over the Tibetan Plateau is more than usual, the winter monsoon will be weaker than usual and vice-versa. Therefore, the effect of winter snow cover on the annual rainfall in Hong Kong can to some extent be dealt with implicitly through the intensity of the winter monsoon. Also, as Tibetan snow cover anomaly data in summarized form does not appear to be readily available on the internet, this factor is not used explicitly in the formulation of the annual rainfall forecast.

7.2.2. Chen (**陳興芳**) and Zhao (**趙振國**) (2000)[30] have also shown that the correlation between the East Asian blocking high and rainfall over the South China coastal areas is weak. This factor will not be furthered considered in forecasting the annual rainfall.

7.2.3. For the same reasons as given in paragraph 5.1.4, the subtropical high will not be used explicitly in predicting annual rainfall in Hong Kong.

7.2.4. There is yet no consensus within the meteorological community regarding the inter-relationship between ENSO and the Asian monsoon (Lau and Wu 2001). These two factors will be used explicitly in forecasting the annual rainfall.

7.2.5. A review of the records shows that of the 10 wettest years in Hong Kong, eight coincided with ENSO activity (Table 7.1). This to some extent agrees with the results of Liang (**梁暖培**) and Liang (**梁必騏**) (1995)[27] for Guangdong, and with those of Lou *et al.* (2002) for Macau. Further, of these eight years, six coincided with strong El Niño activity.

7.2.6. The ENSO signal is evident in the results of the spectral analysis of Hong Kong's annual rainfall data from 1884 to 2001 (Fig. 7.2). There is a group of spectral peaks at 2.2, 2.7, 3.4 and 4.5 years. The 2.2-year periodicity could be related to ENSO and also the TBO, and is consistent with Shen and Lau's (1995) finding of a prominent biennial signal in the East Asian summer monsoon rainfall in southeast China. The 3-5 year periodicities correspond to ENSO cycles. The 12.5-year periodicity could be related to the sunspot cycle, and the 29-year periodicity possibly to the PDO mentioned in paragraph 3.11.

7.2.7. The importance of other climatic factors affecting the interannual variability of Hong Kong's rainfall is reflected in the extreme rainfall in 2001 during which only a weak La Niña was present in the first two months of the year.

7.2.8. Scrutiny of past annual rainfall statistics in relation to ENSO activity and strength of the monsoon (as represented by the winter Unified Monsoon Index (UMI) of Lu and Chan (1999) which is a measure of the strength of the meridional wind at 850 hPa over the South China Sea) suggests that the annual rainfall in Hong Kong can be expected to be above normal in years of strong El Niño onset, near normal or above normal in years immediately following El Niño onset irrespective of strength of the El Niño event, and near normal to below normal in all years immediately following La Niña onset irrespective of the strength of the La Niña event. Here near normal is defined as the long-term (1961-2000) mean plus/minus half a standard deviation. For annual rainfall in Hong Kong this is 1958 mm to 2470 mm. Annual rainfall less than 1958 mm is classified as below normal, and over 2470 mm as above normal.

7.2.9. For other years, the strength of the winter monsoon seems to be the dominating factor, reminiscent of the work of Bell (1976). A weak monsoon in the preceding winter is likely to be associated with above normal annual rainfall, neutral monsoon with near normal rainfall, and strong monsoon with normal or below normal rainfall. In particular, the correlation between rainfall and the winter UMI is about 0.76, statistically significant at the 1 % level. The relationship between the strength of the winter monsoon and annual rainfall in Hong Kong is shown in Fig. 7.3. Cai (**蔡學湛**) *et al.* (2000)[31] also found a similar relationship for April to June rainfall in south China.

7.2.10. The relationships between annual rainfall, ENSO and the winter monsoon are summarized in Fig. 7.4 which provides a conceptual model for forecasting annual rainfall in Hong Kong. The next few paragraphs describe the physical basis for these relationships by highlighting the months or seasons showing coherent bias towards more or less rainfall.

7.2.11. As Fig. 7.5a shows, the months with positive rainfall anomalies in strong El Niño onset years are May through August. In these months, Fig. 7.5b shows that a cyclonic anomaly develops over the coast of south China which is a possible cause for the above normal rainfall in Hong Kong.

7.2.12. In the fall of those years with strong El Niño onset, an anomalous anticyclone develops over the western North Pacific (Wang *et. al.* 2000, Wang and Zhang 2002, Lau and Wu 2001). In particular, Wang *et. al.* (2000) has shown that this anticyclone persists till spring or early summer of the following year. They suggest that this anomalous anticyclone is the key system that bridges the impact of El Niño to East Asia, with stronger than usual southwesterlies on the northwestern periphery of the anticyclone bringing anomalously wet conditions which extend from south China northeastwards to the east of Japan. The development of this anticyclone can be attributed to monsoon-ocean interaction, El Niño forcing, as well as tropical-extratropical interaction (Chang *et al.* 2000, Lau and Nath 2000, Wang and Zhang 2002).

7.2.13. Fig. 7.6a shows the composite distribution of rainfall for different months in years immediately following El Niño onset (all cases, including strong and not-strong). The months with the positive rainfall anomalies are February to July, and Fig. 7.6b shows the composite 850 hPa wind anomalies for these months. Along the south China coast, there is an enhanced southwesterly flow ahead of a westerly trough. These southwesterlies are sandwiched between the anomalous anticyclone over the Pacific to the east of the Philippines mentioned in the last paragraph and an anomalous low to the south of the Shandong Peninsula. This enhanced southwesterly flow is a likely cause for the tendency for above normal rainfall in Hong Kong in years immediately following El Niño onset.

7.2.14. For years immediately following La Niña onset, the rainfall variability is less coherent and the anomalies are comparably smaller. The below normal tendency in the annual rainfall is largely due to the negative anomalies in June and July (Fig. 7.7a). It can be attributed to the weaker than usual southwesterly flow (in the form of a northeasterly flow anomaly, Fig. 7.7b) over the northern part of the South China Sea which results in less moisture advection to this area.

7.2.15. Fig. 7.8a shows that in years with *weak* winter monsoon but excluding those with strong El Niño onset, years immediately following El Niño (both strong and not strong) onset and years immediately following La Niña onset, positive rainfall anomalies are mainly found in the months June to August. In these months, a cyclonic anomaly is found to lie along the south China coast (Fig. 7.8b) which is likely to be the cause of the tendency for the above normal rainfall associated with weak winter monsoons.

7.3. Framing of the Forecasts

7.3.1. The experimental forecasts for 2001 and 2002 were framed in the three categories below normal, near normal, and above normal. This is reasonable in view of the large interannual variability in the annual rainfall which range from a minimum of about 901.1 mm to a maximum of about 3343.0 mm, with a standard deviation of about 512 mm. In the 2002 forecast, the probability of the forecast being correct was also estimated and issued. The way the forecast was presented was well received by the public and could be used in the future.

8. The 2001 and 2002 Experimental Seasonal Forecasts

8.1. Formulation of the Forecasts

8.1.1. How a seasonal forecast is constructed is best illustrated by example. The construction of the 2002 forecast is used for this purpose.

8.1.2. The first step involved examining the SST forecasts available on the internet in March (see paragraph 3.15) to assess the likely status of the ENSO event in the coming year. For 2002, 1 member out of the 16 members in the NCEP ensemble SST forecasts suggested strong El Niño onset (i.e., 1/16 or 6.25% probability), 11 suggested the onset of an El Niño event which was not strong (i.e., 11/16 or 68.75% probability), and 4 suggested a neutral year (i.e., 4/16 or 25% probability). The probability for strong La Niña onset or the onset of a La Niña event which was not strong was 0. Thus, the most likely scenario for 2002 was considered as the onset of an El Niño which was not strong within the year.

8.1.3. The next step in the construction of the 2002 forecast was the selection of the appropriate predictors. For tropical cyclone activity, with QBO in the westerly phase during the year and not expected to significantly affect tropical cyclone activity, El Niño would be the only predictor for annual tropical cyclone activity (paragraph 5.2.7).

8.1.4. According to Table 5.1, 10 out of the 12 years with El Niño onset have 4 to 6 tropical cyclones affecting Hong Kong (i.e., necessitating the hoisting of tropical cyclone signals). This holds even when strong El Niño onsets are excluded. For better precision, it was considered desirable to narrow the range of the forecast to 2 instead of 3 consecutive digits i.e., 4 to 5 or 5 to 6 instead of 4 to 6 (see Section 5.3). The opportunity was also taken to use the number of tropical cyclones entering the 500 km radius as an objective criterion following the arguments in paragraphs 5.2.8, 5.2.9 and 5.3.1. The probabilities of 4 to 5 and 5 to 6 tropical cyclones entering the 500 km radius in 2002 were calculated.

8.1.5. To do this, firstly the climatological probabilities of 4 to 5 and 5 to 6 tropical cyclones entering the 500 km radius were computed. In years with strong El Niño onset, the climatological probability of 4 to 5 tropical cyclones entering 500 km radius is 4/5 or 80 %, and of 5 to 6 tropical cyclones entering 500 km radius is 3/5 or 60% (Table 8.1). In years with the onset of an El Nino which was not strong, the climatological probability of 4 to 5 tropical cyclones entering the 500 km radius is 1/7 or 14.3%, and 5 to 6 is 4/7 or about 57.1% (Table 8.2). In neutral years, the corresponding climatological probabilities are 3/8 or about 37.5% and 4/8 or 50% (Table 8.3).

8.1.6. The probability of 4 to 5 tropical cyclones entering the 500 km radius in 2002 was calculated as [(probability of strong El Niño onset in 2002 x climatological probability of 4 to 5 tropical cyclones entering the 500 km radius in such years) + (probability of the onset of an El Niño which was not strong in 2002 x climatological probability of 4 to 5 tropical cyclones entering the 500 km radius in such years) + (probability of neutral year in 2002 x climatological probability of 4 to 5 tropical cyclones entering 500 km radius in neutral years)]. That is [(6.25% x 80%) + (68.75% x 14.3%) + (25% x 37.5%)] or about 24%. Likewise, the probability of 5 to 6 tropical cyclones entering the 500 km radius was calculated to be about 55.5%. The probability of 5 to 6 tropical cyclones necessitating the hoisting of signals, calculated in the same way, was also about 55%. 5 to 6 tropical cyclones, being associated with a highest probability, was the forecast issued for 2002, with the probability rounded to 60%.

8.1.7. For annual rainfall, with the highest probability being for the onset of an El Niño which was not strong in 2002, the strength of the monsoon in December 2001 to February 2002 was selected as the predictor for annual rainfall (paragraph 7.2.9, Fig. 7.4). This strength in terms of the winter Unified Monsoon Index UMI was neutral, and gave a forecast of near normal rainfall from annual rainfall-winter monsoon relationship in Fig. 7.3.

8.1.8. The climatological probability of normal rainfall in strong El Niño onset years is 1/6 or about 17%. The climatological probability of normal rainfall in other years with a neutral winter monsoon is 7/11 or about 64%. Given the rainfall forecasting scheme in Fig. 7.4, the probability of normal rainfall occurring in 2002 was calculated as [probability of strong El Niño onset in 2002 (1/16) x climatological probability of near normal rainfall occurring in strong El Niño onset years (1/6) + probability of no strong El Niño occurring in 2002 (15/16) x climatological probability of near normal rainfall occurring in such years with a neutral winter monsoon (7/11)]. The result is 60.7 %. Thus, near normal rainfall with a probability of about 60% chance of occurrence was the forecast for 2002.

8.2. Dissemination of the 2001 and 2002 Experimental Seasonal Forecasts

8.2.1. In both 2001 and 2002, the seasonal forecasts were disseminated as part of a press release issued on the fourth week of March covering the annual “Meet the Media Session” of the Director of the Hong Kong Observatory. The forecasts were also posted on the Observatory’s website.

8.2.2. The text relating to the experimental forecast in the 2001 press release reads:

> *The current La Niña episode has been weakening since the end of 1999 and is expected to dissipate gradually this year. Hence, we forecast that the number of tropical cyclones affecting Hong Kong will be near normal this year; that is about six. The annual rainfall amount will also be around normal at about 2 200 millimetres.*

8.2.3. The text relating to the experimental forecast in the 2002 press release reads:

> *Indications are that a weak El Niño event may emerge later this year. The HKO's experimental forecast for 2002 is that there is a 60% chance that the annual rainfall will be near normal. There is also a 60% chance that the number of tropical cyclones affecting Hong Kong will be 5 to 6, slightly less than the normal of 6 to 7.*

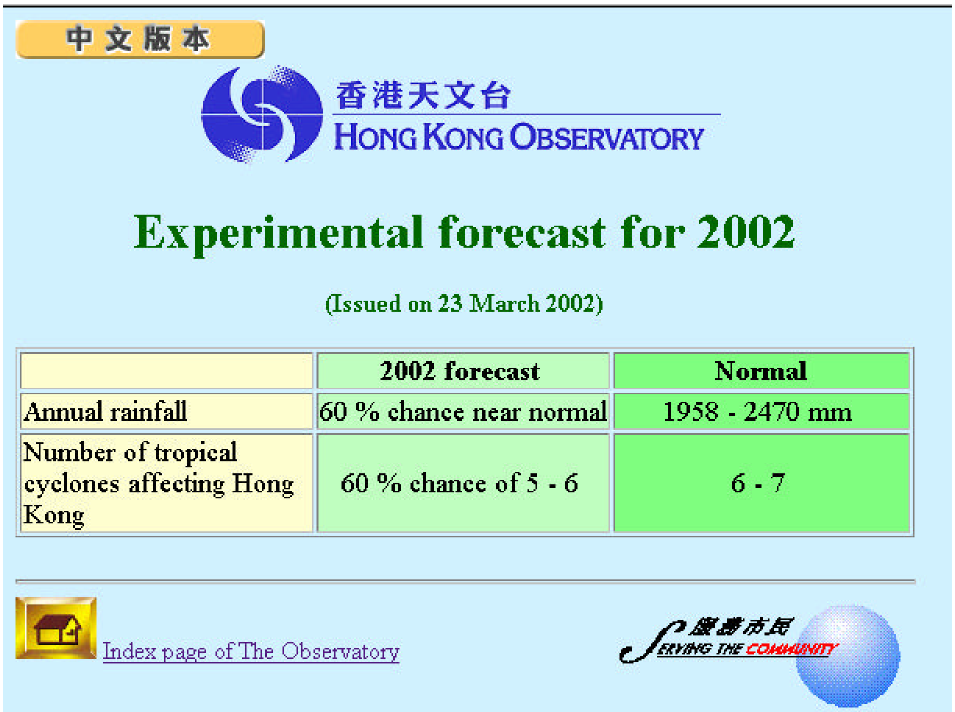
8.2.4. The 2001 and 2002 experimental forecasts as posted on the Observatory's website at http://www.hko.gov.hk/wxinfo/season/season.htm are shown below:

Experimental forecast for 2001

	2001 forecast	Normal
No. of tropical cyclones affecting Hong Kong	Near normal	6 to 7
Annual rainfall	Near normal	2214.3 mm

Index page of The Observatory

Current page last updated on 23 March 2001



Experimental forecast for 2002

(Issued on 23 March 2002)

	2002 forecast	Normal
Annual rainfall	60 % chance near normal	1958 - 2470 mm
Number of tropical cyclones affecting Hong Kong	60 % chance of 5 - 6	6 - 7

8.2.5. It should be noted that in 2002, normal was shown as a range rather than the mean value as in the 2001 forecast. In 2002, the probability of the forecast being correct was also given, which was not done in the 2001 forecast.

8.3. Verification of the 2001 and 2002 Experimental Seasonal Forecasts

8.3.1. Verification showed that tropical cyclone activity in 2001 was well forecast, 6 having affected Hong Kong that year. However, rainfall was under-forecast in that 2001 received 3091.8 mm of rain, 40% above normal and the fourth highest on record. In particular, 1083.6 mm fell in June which was the highest record for that month. A review shows that this extraordinary annual rainfall might be associated with a weaker than normal monsoon in the preceding winter. This monsoon factor was subsequently incorporated into the 2002 experimental rainfall forecast. Had it been used in the 2001 experimental rainfall forecast, the forecast would have been for above normal rainfall and turned out to be correct.

8.3.2. The 2002 experimental forecast was for a below normal to near normal number of 5 to 6 tropical cyclones to affect Hong Kong during the year. Near normal rainfall was forecast. The probability of the forecast being correct was about 60% for both elements.

8.3.3. In 2002, the actual number of tropical cyclones necessitating the hoisting of local tropical cyclone signals in 2002 was 3, fewer than the forecast number which can claim to have the right trend. The actual number of tropical cyclones entering the 500 km radius was 6, within the forecast range. The annual rainfall in 2002 was 2490.0 mm, close to the upper limit of near normal rainfall (2470mm) which was forecast.

8.3.4. These outcomes suggest that some skill exists in predicting the number of tropical cyclones affecting Hong Kong in a year and the annual rainfall.

9. Other Potential Predictors - Teleconnection Indices

9.1. Background

9.1.1. Apart from the climatic factors discussed in the previous Sections, teleconnection patterns also influence climate variability.

9.1.2. Teleconnection patterns are recurring, persistent and large scale patterns of circulation and pressure anomalies spanning the globe (WMO 1999). They reflect large-scale changes in the atmospheric wave patterns, and influence temperature, rainfall, storm tracks, and jet stream locations/ intensity over vast areas. There are some 14 teleconnection patterns over the extratropics in the northern hemisphere. The strength or amplitude of each of these teleconnection patterns is represented by a teleconnection index. Details on these teleconnection patterns have been given by NOAA's Climate Prediction Centre on its website http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.html. The monthly values of these teleconnection indices are also given on that website.

9.1.3. Considerable research has been done on the impact of teleconnection patterns on temperature and precipitation over North America but less has been done for the Asian region. Gray (1993) and Gray *et al.* (2002) have used some of these teleconnection patterns or indices to predict tropical cyclone activity over the Atlantic basin, as have Chan *et al.* (1998, 2001) to predict tropical cyclone activity in the western North Pacific.

9.2. Forecasting for Hong Kong

9.2.1. The teleconnection patterns deserving examination first are those related to SST variability in the tropical Pacific. There are four such teleconnection patterns, namely the Pacific North American (PNA) pattern, the Western Pacific (WP) pattern, the North Pacific (NP) pattern and the Tropical-Northern Hemisphere (T-NH) pattern (WMO 1999). The teleconnection indices associated with these four teleconnection patterns were correlated with number of tropical cyclones affecting Hong Kong in a year and the annual rainfall in Hong Kong to see if there are any connections.

9.2.2. No significant correlation is found between any of the four SST-related teleconnection indices and the number of tropical cyclones affecting Hong Kong in a year.

9.2.3. Of the four SST-related teleconnection indices, the WP teleconnection index (WP index for short) in the preceding October–January is found to be significantly correlated with the annual rainfall in Hong Kong. The correlation coefficient is 0.51, significant at the 1% level.

9.2.4. The WP teleconnection pattern in its positive phase consists of an anomalous low over the Kamchatka and an anomalous high over the western North Pacific and China in winter and spring. In summer and fall, there is an additional anomalous high over the Alaska area (Fig. 9.1).

9.2.5. The regression between the WP index in the proceeding October to January and annual rainfall in Hong Kong between 1961 and 2000 is shown in Fig. 9.2. It gives 2002's annual rainfall as near normal (2395.3 mm), close to the actual of 2490.0 mm.

9.2.6. For probabilities, one can refer to the contingency table in Table 9.1. It shows that when the WP index in the preceding October to January is below normal, Hong Kong is unlikely to see above normal annual rainfall (1/12 chance). On the other hand, when the preceding October-January WP index is above normal, Hong Kong is unlikely to see below normal rainfall (1/15 chance).

9.2.7. Tentatively, Fig. 9.2 and Table 9.1 seem useful for the forecasting of annual rainfall in Hong Kong. The causality between the WP teleconnection pattern and annual rainfall in Hong Kong is being investigated.

9.2.8. Experiments with teleconnection indices not related to tropical Pacific SST suggest that the summer (June-August) rainfall in Hong Kong is correlated with the North Atlantic Oscillation (NAO) index in the preceding April to May. The correlation coefficient is –0.524, significant at the 1% level.

9.2.9. NAO represents the dominant mode of climate variability in the North Atlantic sector and is most prominent in winter (Liu and Yin 2001). In its positive phase it consists of a low over the southeast of Iceland (about 65^0N) and a high over the Atlantic along about 40^0N (Fig. 9.3). The pattern is reversed in the negative phase. NAO mainly influences storm tracks in the North Atlantic and the climate variability of eastern United States and Europe (Wallace and Gutzler 1981, Liu and Yin 2001).

9.2.10. The regression between summer rainfall in Hong Kong and the NAO index in the preceding April to May is shown in Fig. 9.4. It gives around 941.3 mm for the 2002 summer (June-August) rainfall, close to the actual of 924.3 mm. The contingency table in Table 9.2 indicates that when the April to May NAO index is below normal, the chance of below normal rainfall in the summer in Hong Kong (1/13) is considerably smaller than the chance of near normal or above normal rainfall in the summer (both being 6/13). When the index is above normal, the chance of below normal rainfall in the summer in Hong Kong (8/13) is considerably higher than the chance of near normal or above normal rainfall in the summer (3/13 and 2/13 respectively).

9.2.11. The April and May NAO index is usually available on the internet before mid-June. Fig. 9.4 and Table 9.2 can therefore be used for forecasting summer rainfall in Hong Kong. The possibility of using NAO as a predictor for summer rainfall should be examined further.

10. Dynamical Seasonal Forecasting Techniques - Adaptation of a Regional Climate Model

10.1. In 2001, the Hong Kong Observatory successfully adapted a regional climate model from the Experimental Climate Prediction Centre (ECPC) of the Scripps Institution of Oceanography in the United States to an IBM F50 workstation (Hui *et al.* 2001, Chang 2001). The hardware used to run this model is shown in Fig. 10.1. The purposes of adapting this model are to produce, in the long-term, dynamic forecasts of rainfall and temperature in Hong Kong several months ahead by downscaling global model forecasts, and to have in hand a tool for diagnosing and understanding the response of climate in this part of the world to different physical and boundary forcings.

10.2. The regional climate model is based on the regional spectral model of Juang *et al.* (1997). Its forecasts are formulated as spectrally resolved perturbations superimposed on those of a global model operated by the National Center for Environmental Prediction (NCEP) of NOAA (see Roads *et al.* 2001). Such a formulation reduces errors due to lateral boundaries and differences in global and regional model climatologies, making the model attractive for climate forecasting (Hong and Leetma 1999). The initial and boundary data needed by the regional climate model are also provided by the global model.

10.3. The regional climate model is configured to run on an inner domain of 49 x 50 grid points centred on Hong Kong (Fig. 10.2). The horizontal resolution of this inner domain is 15 km, with 18 levels in the vertical. There are 21 x 14 grids in the outer domain (Fig. 10.3). The effective resolution is T62 and there are again 18 levels in the vertical.

10.4. The initial and lateral boundary conditions are downloaded by the Hong Kong Observatory once a week from ECPC via a broadband internet connection. The regional climate model is integrated forward for 12 weeks with the lateral boundary conditions updated every 6 hours. The 12-week forecasts of average rainfall and average temperature at each grid point are then obtained from the results of these 6-hourly integrations using the time averaging facility shown in Fig. 10.4.

10.5. Hui *et al.* (2002) have conducted an ensemble forecasting experiment for May and June rainfall in the years 1998 to 2001. The ensemble members are generated from 4 weekly runs in April of the corresponding year to give forecasts for May and June. The results are shown in Table. 10.1.

10.6. The scaled Kuiper skill score which ranges from 0 to 1, with 0 representing no skill and 1 representing the highest skill (WMO 2000), is used to assess the performance of the above ensemble rainfall forecasts. For May the score is 0.67, and for June 0.5. Thus, the ensemble shows skill for May or one-month lead forecasts, and lesser skill for June or 2-month lead forecasts. This suggests that the model has promise but needs to be improved before it can be used operationally. Runs using historical data are being carried out to compute the model climate for the removal of model bias.

11. Conclusions and Way Forward

11.1 Conclusions

11.1.1. The pilot study made progress in understanding the impact of ENSO and other climate factors on the variability in the local climate. It shows that there is a measure of predictability in the number of tropical cyclones affecting Hong Kong in a year, the time of onset of the tropical cyclone season, and the annual rainfall in Hong Kong. The methods for forecasting these parameters have been developed.

11.1.2. In addition, as part of the pilot study, a database has been constructed to archive data and information needed for seasonal forecasting work, capacity building activities have been carried out, and a regional climate model has been successfully adapted. These have laid the foundation for further work to be done in seasonal forecasting.

11.1.3. The 2001 and 2002 experimental forecasts on the annual rainfall and the number of tropical cyclones expected to affect Hong Kong were widely covered by the media, demonstrating the public's continued interest for information on what the climate of Hong Kong would be like in the coming months. These forecasts compared reasonably well with the actual conditions.

11.1.4. Advantage may be taken of the knowledge gained and predictability found to provide with the community with seasonal forecasts.

11.2. Way Forward

11.2.1. Seasonal forecasts of the annual rainfall in Hong Kong and the annual number of tropical cyclones affecting Hong Kong in a year should be issued because they are of interest to the public and are closely related to the well-being of the community.

11.2.2. Forecasts of the time of onset of the tropical cyclone season in Hong Kong should likewise be prepared and issued as it is also of interest to the public.

11.2.3. The techniques developed so far employ the concept of ENSO years. An alternate approach would be to relate the parameter to be forecast directly to the parameters characterizing ENSO events such as SST over the equatorial central and eastern Pacific, and SOI. Regarding annual rainfall in Hong Kong and the number of tropical cyclones affecting Hong Kong in a year, this work is presently in progress using a systematic approach and cross-validation methods adapted by Wu (2002). Diagnostic studies should be carried out to better understand the physical basis underpinning the predictability.

11.2.4. Teleconnection indices have been found to be potentially useful as predictors for the local climate. Their possible role in seasonal forecasting for Hong Kong merits further study. How different phases of longer period oscillations like the Pacific Decadal Oscillation modulate the impacts of ENSO could also be studied.

11.2.5. The applications of the regional climate model should be further pursued with the long term target of producing consistently skillful forecasts of rainfall and temperature anomalies several months ahead, to meet the needs of utility companies and other users.

---0---0---0---

References[†]

Allan, Rob, Janette Lindesay, David Parker, 1996: *El Niño Southern Oscillation & Climate Variability*. CSIRO, Australia, 405 pp.

An, Soon-Il, and Bin Wang, 2000: Interdecadal change of the structure of the ENSO Mode and its impact on ENSO frequency. *J. Climate*, **13**, 2044-2055.

Anderson, and co-authors, 1999: Present-day capabilities of numerical and statistical models for atmospheric extra-seasonal simulation and prediction. *Bull. Amer. Meteor. Soc.*, **80**, 1349-1361.

Au, C. H., and W. L. Chang, 1998: El Niño and rainfall in Hong Kong. 12th Guangdong-Hong Kong-Macau Severe Weather Conference, 15-17 January, 1998, Hong Kong. Reprint No. 284, Hong Kong Observatory. (Original in Chinese[8]).

Bao, Chenglan, and Yuanzheng Xiang, 1993: Relationship between El Niño event and atmospheric circulation, typhoon activity and flooding. *Proceedings of the Second Conference on East Asia and Western North Pacific Meteorology and Climate*, W. J. Kyle and C. P. Chang (Editors), 239-249.

Barnston, Anthony G., Michael H. Glantz, and Yuxiang He, 1999: Predictive skill of statistical and dynamical climate models in SST forecasts during the 1997-1998 El Niño episode and the 1998 La Niña onset. *Bull. Amer. Meteorol. Soc.*, **80**, 217-243.

Bell, G. J., 1974: Quasi-biennial oscillations in the tropical troposphere. Occasional Paper No. 28, Hong Kong Observatory.

Bell, G. J., 1976: Seasonal forecasts of Hong Kong summer rainfall. *Weather*, **31,** 208-212.

Brigg, G. R., 1990: El Niño and the Southern Oscillation. *Weather*, **45**, 2-8.

Cai, Xuezhan, Jinjing Xu, and Bin Wu, 2000: The canonical flood/drought during the pre-flood season in South China and its some physical factors during the earlier stage. *Research in the Methodologies for the Diagnostic Analysis and Forecasting of Serious Drought/Flood and Low Temperature*, Anjian Sun, Guoxiong Wu, and Yongkang Li (Editors). China Meteorological Press, 166-173. (Original in Chinese[31]).

Chan, J. C. L., 1995: Tropical cyclone activity in the western North Pacific in relation to stratospheric quasi-biennial oscillation. *Mon. Wea. Rev.*, **123**, 2567- 2571.

Chan, Johnny C. L., 2000: Tropical cyclone activity over the western North Pacific associated with El Niño and La Niña events. *J. Climate*, **13**, 2960-2972.

[†] Include English translations of references originally in Chinese which are numbered according to the order of appearance in the text. A list of these references in their original language and in the numerical order they appear in the text is appended to this Section.

Chan, J. C. L., J. E. Shi, and C. M. Lam, 1998: Seasonal forecasting of tropical cyclone activity over the western North Pacific. *Wea. Forecasting*, **16**, 491-498.

Chan, Johnny C. L., and Jiu-En Shi, 1999: Prediction of the summer monsoon rainfall over South China. *Int. J. Climatol.*, **19,** 1255-1265.

Chan, J. C. L., J. E. Shi, and K. S. Liu, 2001: Improvements in the seasonal forecasting of tropical cyclone activity over the western North Pacific. *Wea. Forecasting*, **16**, 491-498.

Chan, Johnny, 2002: 2002 prediction of seasonal tropical cyclone activity over the western North Pacific and the South China Sea, and the number of landfalling tropical cyclones over south China. [Available on the Internet at http://aposf02.cityu.edu.hk/~mcg/tc_forecast/2002_forecast_APR.htm].

Chang, C. P., and Tim Li, 2000: A theory for the tropical tropospheric biennial oscillation. *J. Atmos. Sci.*, **57**, 2209-2224.

Chang, C. P., Yongshen Chang, and Tim Li, 2000: Interannual and interdecadal variations of the east Asian Monsoon and tropical Pacific SSTs. Part 1: Roles of the subtropical ridge. *J. Climate*, **13**, 4310-4325.

Chang, W. L., 1999: Some impacts of El Niño and La Niña events on the weather of Hong Kong. Workshop on the Impact of the El Niño Southern Oscillation (ENSO) /La Niña on Meteorology and Hydrology in the Typhoon Committee Area. 29 June-1 July 1999, Macau. Reprint No. 310, Hong Kong Observatory.

Chang, W. L., 2001: Implementation of a Regional Climate Model at the Hong Kong Observatory. *Research Activities in Atmospheric and Oceanic Modelling*, H. Ritchie (Editor). Report No. 31, CAS/JSC Working Group on Numerical Experimentation, WMO/TD-No. 1064, World Meteorological Organization, Geneva, Switzerland.

Chang, W. L., and M. C. Wu, 2001: Low frequency oscillations during Hong Kong' s rainy season in 1998. Scientific Conference on the South China Sea Monsoon Experiment (SCSMEX), 17-20 April, 2001, Shanghai, China. Reprint No. 430, Hong Kong Observatory.

Chao, Jiping, 1993: *ENSO Dynamics*. China Meteorological Press, 309 pp. (Original in Chinese[1]).

Chen, Juying, 1991: *Analysis of Droughts and Floods and Long-range Forecasting Research in China*. Agricultural Press, 341 pp. (Original in Chinese[3]).

Chen, Lianshou, and Yihui Ding, 1979: *An Introduction to Tropical Cyclones in the Western North Pacific*. Science Press, 491 pp. (Original in Chinese[19]).

Chen, Xinfang, and Zhenguo Zhao, 2000: *Research in and Applications of the Prediction of Rainfall in the Flood Season in China*. China Meteorological Press, 241 pp. (Original in Chinese[30]).

Dalcher, Amnon, Eugenia Kalnay, and Ross Hoffman, 1988: Medium range lagged average forecasts. *Mon. Wea. Rev.*, **116,** 402-416.

Ding, Yihui, 1992: Summer monsoon rainfalls over China. *J. Meteor. Soc. Japan,* **70**, 373-396.

Ding, Yihui, 1994: *Monsoons over China*. Kluwer Academic Publishers. 419 pp.

Ding, Yihui, 2001: *Lectures on Seasonal Forecasting*. 21-25 May 2001, Hong Kong Observatory. (Original in Chinese[14]).

Dong, Min, and Coauthors, 2000: Development and applications of atmospheric circulation models for seasonal forecasting. *Developments in Operational Dynamical Models for Seasonal Forecasting,* Vol. 2, *Research in Seasonal Forecasting*, Project Office Expert Team (Editors). China Meteorological Press, 63-69. (Original in Chinese[13]).

ECMWF, 1999: *Proceedings of a Workshop Held at ECMWF on Applications of Seasonal Forecasting*. European Centre for Medium-Range Weather Forecasts, 14-15 June, 1999.

Fu, Congbin, and Teng Xinglin, 1993: Relationship between summer climate in China and the El Nino/Southern oscillation Phenomenon. *Frontiers in Atmospheric Sciences*, Edited by Institute of Atmospheric Physics, Chinese Academy of Sciences. Allerton Press, 166-178.

Gates, and co-authors, 1999: An overview of the results of the Atmospheric Model Intercomparison Project (AMIP 1). *Bull. Amer. Meteor. Soc.*, **80**, 29-55.

Glantz, M. H., R. W. Katz, and N. Nicholls, 1991: *Teleconnections Linking Worldwide Climate Anomalies*. Cambridge University Press, 535pp.

Glantz. Michael H. (Editor), 1998: Review of the causes and consequences of cold events - Executive Summary of the La Niña Summit Report. Available on the Internet at (http://www.esig.ucar.edu/lanina/exec_summ.html).

Goddard, L., S. J. Mason, S. E. Zebiak, C. F. Ropelewski, R. Basher, and M. A. Cane, 2001: Current approaches to seasonal to interannual climate predictions. *Int. J. Climatol.*, **21**, 1111-1152.

Gray, W. M., 1993: Seasonal forecasting. *Global Guide to Tropical Cyclone Forecasting*. Tropical Cyclone Programme Report No. TCP-31, World Meteorological Organization Technical Document WMO/TD-N0. 560, World Meteorological Organization, Geneva, Switzerland.

Gray, William M., Christopher W. Landsea, Eric Blake, and Philip Klotzbach, 2002: Extended range forecasts of Atlantic seasonal hurricane activity and US landfall strike probability for 2002. [Available on the Internet at http://typhoon.atmos.colostate.edu/forecasts/2002/fcst2002/].

Hong, Song-You, and Ants Leetma, 1999: An evaluation of NCEP RSM for regional climate modeling. *J. Climate*, **12**, 592-609.

Huang, Ronghui, Zhang Renhe, and Zhang Qingyun, 2000: The 1997/1998 ENSO cycle and its impact on summer climate in East Asia. *Adv. Atm. Sci.*, **17**, 348-362.

Hui, T. W., and W. L. Chang, 2000: Seasonal forecasting by analogue – the experience of Hong Kong, China. Workshop on Flood Forecasting, 6-9 November 2000, Beijing, China. Reprint No. 481, Hong Kong Observatory.

Hui, T. W., K. H. Yeung, and W. L. Chang, 2001: Adaptation of NCEP RSM model for seasonal forecasting. Third RSM International Conference, Taipei, 23-27 July 2001. Reprint No. 436, Hong Kong Observatory.

Hui, T. W., W. L. Chang, and Karen K. Y. Shum, 2002: Seasonal forecasting for Hong Kong with ensembles from a regional model – some preliminary results. 2nd APCN Working Group Meeting, 11-13 June, 2002, Seoul, Republic of Korea. Reprint No. 480, Hong Kong Observatory.

IPCC, 2001: *Climate Change 2001: the Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J. T. Houghton *et al.* (Editors). Cambridge University Press, 881 pp.

Ji, Jinjun, 1990: Land-air interaction and the seasonal forecasts of droughts and floods. *The Climate Research of Drought and Flood*, Duzheng Ye and Ronghui Huang (Editors). China Meteorological Press, 101-110. (Original in Chinese[28]).

Juang, Hann-Ming Henry, Hong Song-You, and Masao Kanamitsu, 1997: The NCEP regional spectral model: an update. *Bull Amer. Meteor. Soc.*, **78**, 2125-2143.

Krishnamurti, T. N., C. M. Kishtawal, T. E. LaRow, D. R. Bachiochi, Z. Zhang, E. Williford, S. Gadgil, and S. Surendran, 1999: Improved weather and seasonal climate forecasts from multi-model superensemble. *Science*, **285,** 1548-1550.

Kung, Terence, and Joly Ho, 2002: A conceptual model for forecasting the onset of the tropical cyclone season in Hong Kong. 16th Guangdong - Hong Kong - Macau Seminar on Meteorological Science and Technology, 30-31 January 2002, Guangzhou. Reprint No. 460, Hong Kong Observatory. (Original in Chinese[9]).

Lam, C. Y., 1993: El Niño/Southern Oscillation and spring weather in Hong Kong. *HKMetSoc Bulletin*, **3**, 3-13.

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

Lau, K. M., and H. T. Wu, 2001: Principal modes of rainfall-SST variability of the Asian summer monsoon: a reassessment of the monsoon-ENSO relationship. *J. Climate,* **14,** 2880-2895.

Lau, K. M., and Hengyi Weng, 2001: Coherent modes of global SST and summer rainfall over China: An assessment of regional impacts of the 1997-98 El Niño. *J. Climate,* **14,** 1294-1308.

Lau, Ngar-Cheung, and Mary Jo Nath, 2000: Impact of ENSO on the variability of the Asian-Australian monsoons as simulated in GCM experiments. *J. Climate*, **13**, 4287-4309.

Lau, R., and M. Y. Chan, 1989: The Royal Observatory long range rainfall forecast methods. *Proceedings of the International Conference on East Asia and Western Pacific Meteorology and Climate,* P. Sham and C. P. Chang (Editors). World Scientific, 485-493.

Lau, R., 1992: Equatorial stratospheric flow patterns and quasi-biennial/penta-annual oscillations. *Proceedings of the 2nd International Conference on East Asia and Western Pacific Meteorology and Climate*, P. Sham and C. P. Chang (Editors). World Scientific, 485-493.

Leung, John Y.K., and M. C. Wu, 2000: Low frequency oscillation of the winter monsoon in Hong Kong, China. Joint Meeting on Seasonal Prediction of the East Asian Monsoon, 21-22 November 2000, Beijing China. Reprint No. 367, Hong Kong Observatory.

Leung, Y. K., and W. M. Leung, 2002: Effect of ENSO on the number of tropical cyclones affecting Hong Kong. Workshop on the Network System for monitoring and Predicting ENSO Event and Sea Temperature Structure of the Warm Pool in the Western Pacific Ocean, Macau, China, 5-7 February 2002. Reprint No. 453, Hong Kong Observatory.

Li, Chongyin, Yuxiang Chen, and Chongguang Yuan, 1988: An important causative factor of El Niño events – frequent activities of strong cold waves in East Asia. *Special Issue, Scientia Atmospherica Sinica*, 125-132. (Original in Chinese[2]).

Li, Chongyin, Sun Shuqing, and Mu Mingquan, 2001: Origin of the TBO – Interaction between anomalous East Asian Winter Monsoon and the ENSO cycle. *Adv. Atm. Sci.*, **18,** 554-566.

Li, Weijing, 2000: Developments in dynamical forecasts in the extended range of a month. *Developments in Operational Dynamical Models for Seasonal Forecasting,* Vol. 2, *Research in Seasonal Forecasting,* Project Office Expert Team (Editors). China Meteorological Press, 3-9. (Original in Chinese[12]).

Liang, Nuanpei, and Biqi Liang, 1995: The El Niño event and rainfall variation in Guangzhou. *Tropical Oceanology*, **14**, 18-23. (Original in Chinese[27]).

Liu, Chunxia, 2000a: Advances on the research of climate rules of tropical cyclones in Guangdong and their prediction. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 27-33. (Original in Chinese[16]).

Liu, Chunxia, 2000b: Study of formation causes for anomalies of annual tropical cyclone frequency in Guangdong. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 242-253. (Original in Chinese[17]).

Liu, Chunxia, 2000c: Short-term climatological predictions of tropical cyclones in Guangdong - the application of the forecasting method using analogues of phase space. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 266-271. (Original in Chinese[20]).

Liu, Chunxia, 2000d: Wavelet analysis of annual variation of tropical cyclones in Guangdong. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 233-241. (Original in Chinese[22]).

Liu, Jinping, and Yan Li, 1999: El Niño and flood and typhoon landed in China. Workshop on the Impact of the El Niño Southern Oscillation (ENSO)/La Niña on Meteorology and Hydrology in the Typhoon Committee Area. 28 June – 1 July 1999, Macau.

Liu, Yongqiang, and Yihui Ding, 1995: Reappraisal of the influence of ENSO events on seasonal precipitation and temperature in China. *Scientia Atmospherica Sinica*, **19**, 200-208. (Original in Chinese[4]).

Liu, X. D., Z. Y. Yin, 2001: Spatial and temporal variation of summer precipitation over the eastern Tibetan Plateau and the North Atlantic Oscillation. *J. Climate*, **14**, 2896-2909.

Lou, Mei Meng, Soi Kun Fong, and Hao I Pan, 2002: Impact of El Niño and La Niña on precipitation and temperature in Macao. *Selected Papers of the Fourth Conference on East Asia and Western Pacific Meteorology and Climate*, C. P. Chang, Guoxiong Wu, Ben Jou, and C. Y. Lam (Editors). World Scientific, 122-130.

Lu, Er, and Johnny C. L. Chan, 1999: A unified monsoon index for South China. *J. Climate*, **12,** 2375-2385.

Mantua, Nathan J., Steven R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteor. Soc.*, **78**, 1069-1079.

Marquardt, C., and B. Naujokat, 1997: An update of the equatorial QBO and its variability. 1st SPARC General Assembly, Melbourne Australia. WMO/TD-No.814, Vol. 1, 87-90, World Meteorological Organization, Geneva, Switzerland.

Meehl, Gerald A., and Julie M. Arblaster, 2002: The Tropospheric Biennial Oscillation and Asian-Australian monsoon rainfall. *J. Climate*, **15**, 722-744.

Murphy, James, 1999: An evaluation of statistical and dynamical techniques for downscaling local climate. *J. Climate*, **12**, 2256-2284.

National Climate Centre, 1998: *The Severe Flooding in China in '98 and Climate Anomalies.* National Climate Centre, China Meteorological Administration. China Meteorological Press, 139 pp. (Original in Chinese[5]).

Neelin, J. David, Fei-Fei Jin, and Hsin-Hsin Syu, 2000: Variations in ENSO phase locking. *J. Climate*, **13**, 2570-2590.

Palmer, T. N., and D. L. T. Anderson, 1994: The prospects for seasonal forecasting- a review paper. *Q. J. R. Meteorol. Soc.*, **120**, 755-793.

Peng, Gongbing, and Coauthors, 1992: *Climate and Ice-Snow Cover.* China Meteorological Press, 349 pp. (Original in Chinese[29]).

Philander, S. George, 1990: *El Niño, La Niña and the Southern Oscillation.* Academic Press, 293 pp.

Roads, John O., Shyh-Chin Chen, and Francis Fujioka, 2001: ECPC's weekly to seasonal forecasts. *Bull. Amer. Meteor. Soc.*, **82**, 639-658.

Rockett, Paul, and Mark Saunders, 2002: Extended range forecast for Northwest Pacific typhoon activity in 2002. [Available on the Internet at http://tropicalstormrisk.com].

Ropelewski, C. F., and Halpert, M. S., 1987: Global and regional scale precipitation associated with El Niño/Southern Oscillation. *Mon. Wea. Rev.*, **115**, 1606-1626.

Shen, Suhung, and K. M. Lau, 1995: Biennial oscillation associated with the East Asian Summer Monsoon and tropical sea surface temperatures. *J. Meteor. Soc. Japan*, **73**, 105-124.

Shi, Neng, and Jiade Zhou, 1989: A statistical analysis of typhoon activities over the South China Sea and ENSO. *Meteorology*, **15**, 9-14. (Original in Chinese[15]).

Shukla, J., 1998: Predictability in the midst of chaos: a scientific basis for climate forecasting. *Science*, **282**, 728-731.

Shukla, J., and co-authors, 2000: Dynamical seasonal prediction. *Bull. Amer. Meteor. Soc.*, **81**, 2593-2606.

Stone, Doug, 2001: AMS Statement – Seasonal to interannual climate prediction. *Bull. Amer. Meteorol. Soc.*, **82**, 701-710.

Tian, Cuiying, 1999: Impacts of ENSO on hydrology and meteorology in China. Workshop on the Impact of the El Niño Southern Oscillation (ENSO)/La Niña on Meteorology and Hydrology in the Typhoon Committee Area. 29 June – 1 July 1999, Macau.

Trenberth, K. E., and T. J. Hoar, 1996: The 1990-1995 El Niño-Southern Oscillation event: longest on record. *Geophys. Res. Lett.*, **23,** 57-60.

Trenberth, Kevin E., 1997: Short term climate variations: recent accomplishments and issues for future progress. *Bull. Amer. Meteor. Soc.*,

78, 1081-1096.

Wallace, John M., David S. Gutzler, 1981: Teleconnections in geopotential height field during the northern hemisphere winter. *Mon. Wea. Rev.*, **109**, 784-812.

Wang, Bin, Renguang Wu, and Xiouhua Fu, 2000: Pacific – East Asian Teleconnection: How does ENSO affect East Asian Climate? *J. Climate*, **13**, 1517-1536.

Wang, Bin, Johnny C. L. Chan, 2002: How strong ENSO events affect tropical storm activity over the western North Pacific. *J. Climate*, **15,** 1609-1625.

Wang, Bin, and Qin Zhang, 2002: Pacific-East Asian teleconnection. Part II: How the Philippine Sea anomalous anticyclone is established during El Niño development. *J. Climate*, **15**, 3252-3265.

Wang, Huijun, and co-authors, 2001: Recent researches on the short-term climate prediction at IAP – a brief review. *Adv. Atmos. Sci.*, **18**, 929-936.

Wang, Shaowu, and Jinhong Zhu, 2001: A review of seasonal climate prediction. *Adv. Atm. Sci.*, **18**, 197-208.

Webster, and Palmer, 1997: The past and future of El Niño. *Nature*, **390**, 562-564.

Weng, Hengyi, K. M. Lau, and Yongkang Xue, 1999: Multi-scale summer rainfall variability over China and its long term link to global sea surface temperature variability. *J. Meteor. Soc. Japan*, **77**, 845-857.

Winkler, Robert L., and Allan H. Murphy, 1985: Decision analysis. *Probability, Statistics, and Decision Making in the Atmospheric Sciences*, Murphy, Allan H., and Richard W. Katz (Editors). Westview Press, 493-524.

WMO, 1999: *Long-range Forecasting Report for 1997-1998*. WMO/TD-No. 967, World Meteorological Organization, Geneva, Switzerland.

WMO, 1999: *The 1997-1998 El Niño event: A Scientific and Technical Retrospective.* WMO No. 905, World Meteorological Organization, Geneva, Switzerland.

WMO, 2000: Draft standardized verification system (SVS) for long-range forecasts (LRF). Commission for Basic Systems, World Meteorological Organization, Geneva, Switzerland.

WMO, 2002: WMO Statement on the Scientific Basis for, and Limitations of, Weather and Climate Forecasting. World Meteorological Organization, Geneva, Switzerland.

Wright, P. B., 1985: The Southern Oscillation: An ocean-atmosphere feedback system? *Bull. Amer. Meteor. Soc.*, **66**, 398-412.

Wu, Guoxiong, and Ngar-Cheung Lau, 1992: A GCM simulation of the relationship between tropical-storm formation and ENSO. *Mon. Wea. Rev.*, **120**, 958-977.

Wu, M. C., W. L. Chang, and W. M. Leung, 2002: Impact of El Niño-Southern Oscillation (ENSO) events on tropical cyclone landfalling activity in the western North Pacific. Sixth Joint Meeting of Prediction of the East Asian Summer Monsoon, 16-18 May 2002, Beijing, China. (*Paper submitted to Journal of Climate)*.

Wu, Man-Chi, 2002: Prediction of rainfall during the dry season in Hong Kong. Fourth Workshop on Regional Climate Prediction and Applications from Tropical Pacific Islands and Rim. University of Oklahoma, Norman, Oklahoma, 27 May to 5 July 2002. *(Paper being reviewed by the Workshop's external referees).*

Wu, Shangsen, and Coauthors, 2000: Relation between the El Niño events and climate in Guangdong. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 301-307. (Original in Chinese[18])

Xie, Dingsheng, and Coauthors, 2000: Prediction of annual and monthly frequency of tropical cyclones. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 272-277. (Original in Chinese[21])

Xie, Jiongguang, 2000: Analysis and forecast of the tropical cyclones that made the yearly first and last landfall in Guangdong. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 261-264. (Original in Chinese[24])

Xie, Jiongguang, and Ji Zhongping, 2000: Singular spectral analysis for tropical cyclones that landed in Guangdong. *Research in Seasonal Forecasting for Guangdong Province,* Huang Zengming, Xie Jiongguang, Wu Shangsen, and Liang Jianyin (Editors). China Meteorological Press, 254-260. (Original in Chinese[23]).

Xu, Lizhang, 1994: The relationship between El Niño events and drought/flood of each area in Guangdong during the summer season. *Tropical Oceanology,* **13,** 33-40. (Original in Chinese[26]).

Zhang, Renhe, 2000: A diagnostic study of the effect of El Niño events on rainfall in China. *Development of an Integrated Operational Monitoring, Forecasting and Service Delivery System for Climate on seasonal Time Scales,* Vol. 4, *Research in Seasonal Forecasting,* Project Office Expert Team (Editors). China Meteorological Press, 69-79. (Original in Chinese[25]).

Zhang, Renhe, Akimasa Sumi and Masahide Kimoto, 1999: A diagnostic study of the impact of El Niño on the precipitation of China. *Adv. Atmo. Sci.*, **16**, 229-241.

Zhang, Chidong, and Jonathan Gottschalk, 2002: SST anomalies and the Madden-Julian Oscillation in the equatorial Pacific. *J. Climate,* **15,** 2429-2445.

Zhao, Qigeng, 1999: *Numerical Modelling of Ocean Circulations and Coupled Ocean-Atmosphere Systems*. China Meteorological Press, 216 pp. (Original in Chinese[10]).

Zhao Zhenguo, 1996: Progress in the forecasting of droughts and floods in China's flood season. *Research in Climate Forecasting*, Wang Shaowu (Chief Editor). China Meteorological Press, 84-93. (Original in Chinese[6a]).

Zhao Zhenguo (Editor), 1999: *Droughts and Floods in Summer in China and the Associated Circulation Patterns.* China Meteorological Press, 297 pp. (Original in Chinese[6b]).

Zhao Zhenguo, and Coauthors, 2000: El Niño, La Niña events and their possible impacts on the East Asian circulation and the climate of China. *Development of an Integrated Operational Monitoring, Forecasting and Service Delivery System for Climate on Seasonal Time Scales,* Vol. 4, *Research in Seasonal Forecasting,* Project Office Expert Team (Editors). China Meteorological Press, 313-321. (Original in Chinese[7]).

Zhao, Zongci, and Coauthors, 2000: A model for forecasting the interannual variation in ENSO events. *Development of Operational Dynamical Models for Seasonal Forecasting,* Vol. 2, *Research in Seasonal Forecasting,* Project Office Expert Team (Editors). China Meteorological Press, 323-333. (Original in Chinese[11]).

List of Publications in Chinese

1. **巢紀平**, 1993: ***厄爾尼諾和南方濤動動力學***. **氣象出版社**, **共** 309 **頁**.
2. **李崇銀**, **陳于湘**, **袁重光**, 1988: El Niño **事件發生的一個重要原因 - 東亞寒潮的頻煩活動**. ***大氣科學特刊***, **氣象出版社**, 125-131.
3. **陳菊英**, 1991: ***中國旱澇的分析和長期預報研究***. **農業出版社**, **共** 341 **頁**.
4. **劉永強**, **丁一匯**, 1995: ENSO **事件對我國季節降水和溫度的影響**. ***大氣科學***, **19**, 200-208.
5. **中國氣象局國家氣候中心**, 1998: *'98* ***中國大洪水與氣候異常***. **氣象出版社**, **共** 137 **頁**.

6a. **趙振國**, 1996: **我國汛期旱澇趨勢預測進展**. ***氣候預測研究***, **王紹武主編**. **氣象出版**, 84-93.

6b. **趙振國** (**主編**), 1999: ***中國夏季旱澇及環境場***. **氣象出版社**, **共** 297 **頁**.

7. **趙振國**, **陳國珍**, **王永光**, **劉海波**, **許力**, 2000: **厄爾尼諾, 拉妮娜事件對東亞環流和中國氣候的可能影響**. ***我國短期氣候預測系統的研究之四 - 短期氣候監測、預測、服務綜合業務系統的研制***, **項目辦公室項目執行專家組編**. **氣象出版社**, 313-321.
8. **區展衡**, **張文瀾**, 1998: **厄爾尼諾與香港的降水**. **第十二屆粵港澳重要天氣研討會**, 1998 **年** 1 **月** 15-17 **日**, **香港**. Reprint No. 284, Hong Kong Observatory.
9. **龔穎恆**, **何嘉玲**, 2002: **預測香港颱風季節何時開始**[**初旋出現**]**的概念模式**. **第十六屆粵港澳氣象科技研討會**, **廣州**, 2002 **年** 1 **月** 30-31 **日**. Reprint No. 460, Hong Kong Observatory.
10. **趙其庚**, 1999: **海洋環流及海汽耦合系統的數值模擬**. **氣象出版社**, **共** 216 **頁**.
11. **趙宗慈等**, 2000: ENSO **年際變化預測模式研制**. ***我國短期氣候預測系統的研究之二 - 短期氣候預測業務動力模式的研制***, **項目辦公室項目執行專家組編**. **氣象出版社**, 323-333.
12. **李維京**, 2000: **月尺度動力延伸預報研究發展**. ***我國短期氣候預測系統的研究之二 - 短期氣候預測業務動力模式的研制***, **項目辦公室項目執行專家組編**. **氣象出版社**, 3-9.
13. **董敏** *et al.*, 2000: **季節預測大氣模式研制和應用發展**. ***我國短期氣候預測系統的研究之二 - 短期氣候預測業務動力模式的研制***, **項目辦公室項目執行專家組編**. **氣象出版社**, 63-69.
14. **丁一匯**, 2001: **短期氣候講座提綱**. 2002 **年** 5 **月** 21-25 **日**, **香港天文台**.

15 施能, 周家德, 1989: ENSO 與南海台風活動的統計分析. *氣象*, **15,** 9-14.

16. 劉春霞, 2000a: 廣東熱帶氣旋氣侯規律和預測研究進展. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 27-33.

17. 劉春霞, 2000b: 廣東熱帶氣旋年頻數異常分析. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 242-253.

18. 吳尚森, 謝炯光, 李曉娟, 紀忠平, 丁偉鈺, 李慧君, 2000: 厄爾尼諾事件與廣東氣候的關係. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 301-307.

19. 陳聯壽, 丁一匯, 1979: *西太平洋颱風概論*. 科學出版社, 共 491 頁.

20. 劉春霞, 2000c: 廣東熱帶氣旋短期氣候預測: 相空間相似預報方法的應用. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 266-271.

21. 謝定升, 張曉暉, 梁風儀, 2000: 熱帶氣旋的年、月頻數預測. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 272-277.

22. 劉春霞, 2000d: 廣東熱帶氣旋年際變化的小波分析. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 233-241.

23. 謝炯光, 紀忠平: 2000: 登陸廣東熱帶氣旋的奇異譜分析. *廣東省短期氣候預測研究*, 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 255-260.

24. 謝炯光, 2000: 登陸廣東的初、終熱帶氣旋分析和預測. *廣東省短期氣候預測研究*. 黃增明, 謝炯光, 吳尚森, 梁建茵 (主編). 氣象出版社, 261-264.

25. 張人禾, 2000: 厄爾尼諾對我國降水影響的診斷分析. *我國短期氣候預測系統的研究之四 - 短期氣候監測、預測、服務綜合業務系統的研制*, 項目辦公室項目執行專家組編. 氣象出版社, 69-79.

26. 許麗章, 1994: El Niño 事件與廣東各區域夏季旱澇的關係. *熱帶海洋*, **13,** 33-40.

27. 梁暖培, 梁必騏, 1995: 厄爾尼諾事件與廣州降水. *熱帶海洋*, **14,** 18-23.

28. 季勁鈞, 1990: 地氣相互作用與旱澇長期預報. *旱澇氣候研究進展*, 葉篤正, 黃榮輝主編. 氣象出版社, 101-110.

29. 彭公炳, 李晴, 錢步東, 1992: *氣候與冰雪覆蓋 - Climate and Ice-Snow Cover*. 氣象出版社, 349 pp.

30. 陳興芳, 趙振國, 2000: *中國汛期降水預測研究及應用*. 氣象出版社, 共 241 頁.
31. 蔡學湛, 許金鏡, 吳濱, 2000: 華南前汛期典型旱澇與前期若干物理因子的關係. *嚴重旱澇與低溫的診斷分析和預測方法研究*, 孫安健, 吳國雄, 李永康主編. 氣象出版社, 166-173.

Figures

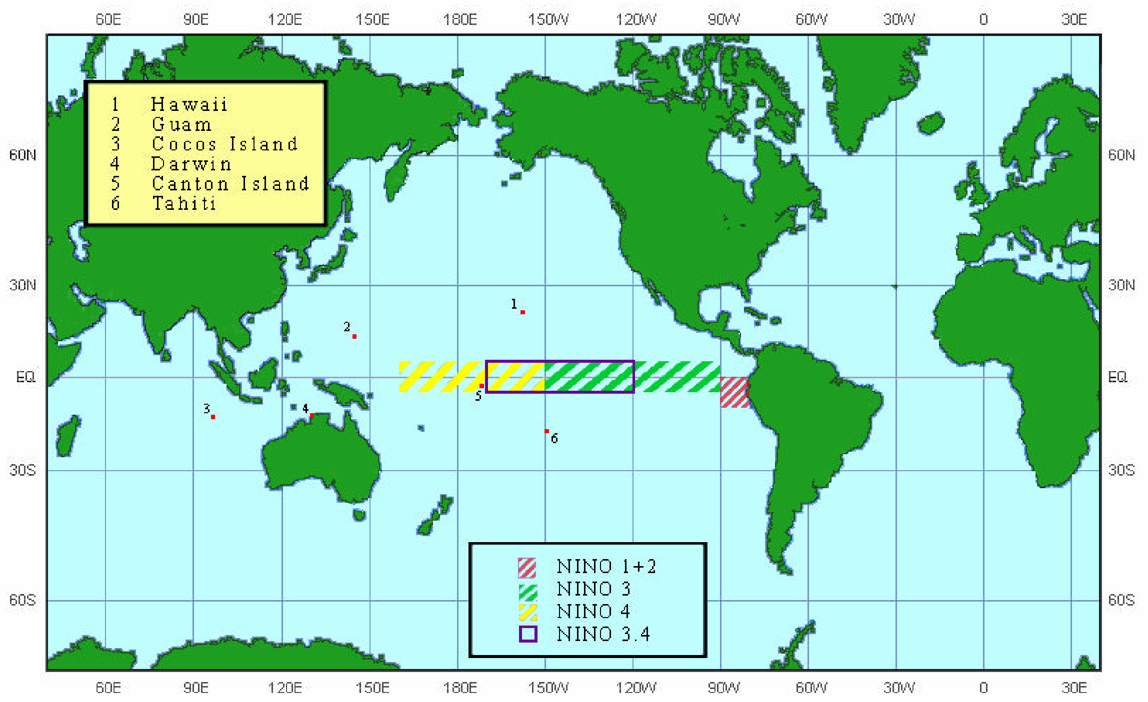


Fig. 3.1. Map of the various Niño regions.

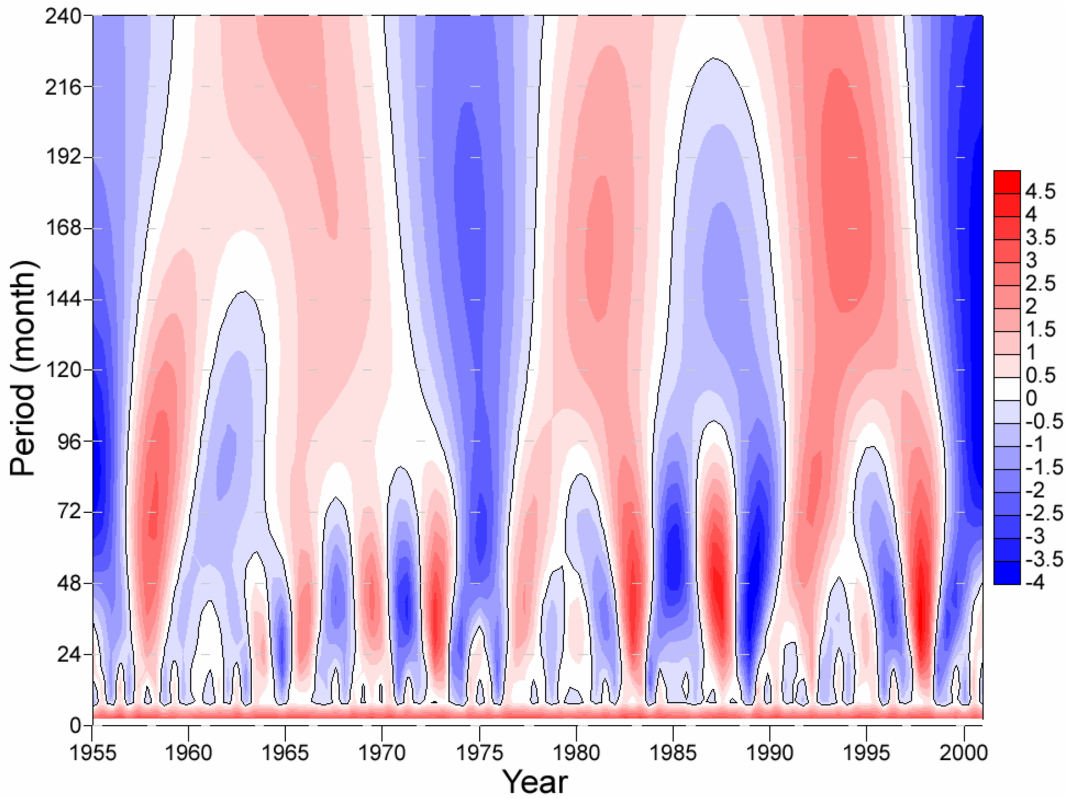


Fig. 3.2. Wavelet analysis of sea surface temperatures in the equatorial central Pacific (Niño 3.4 area).

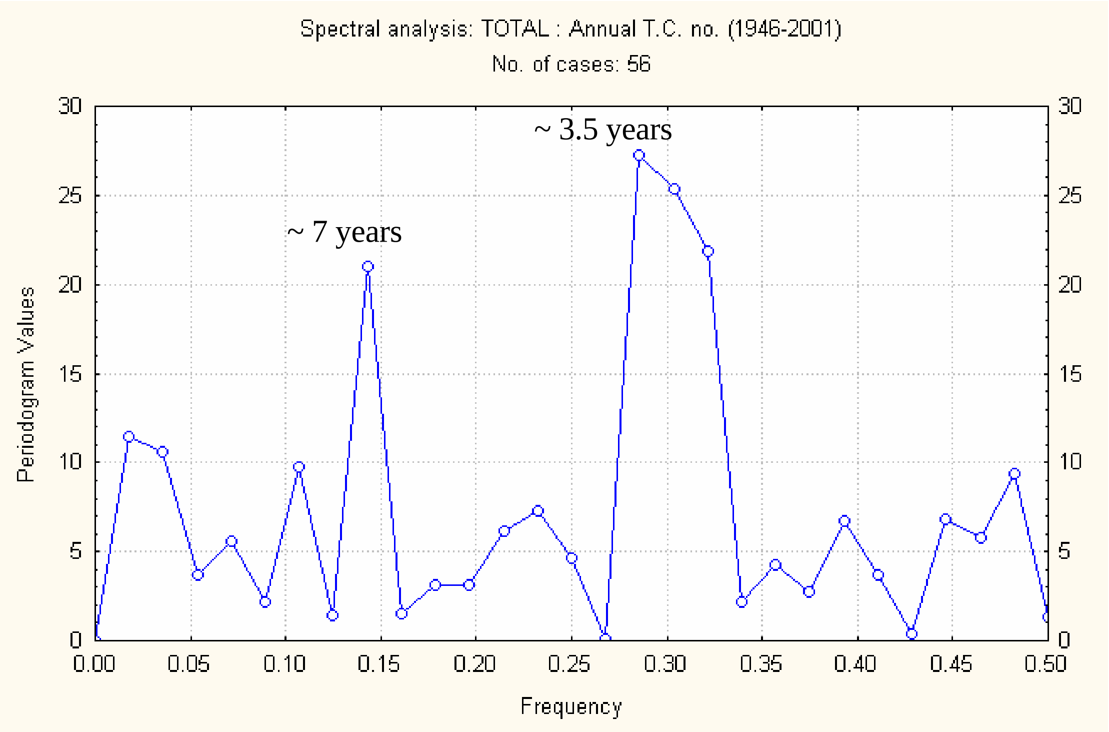
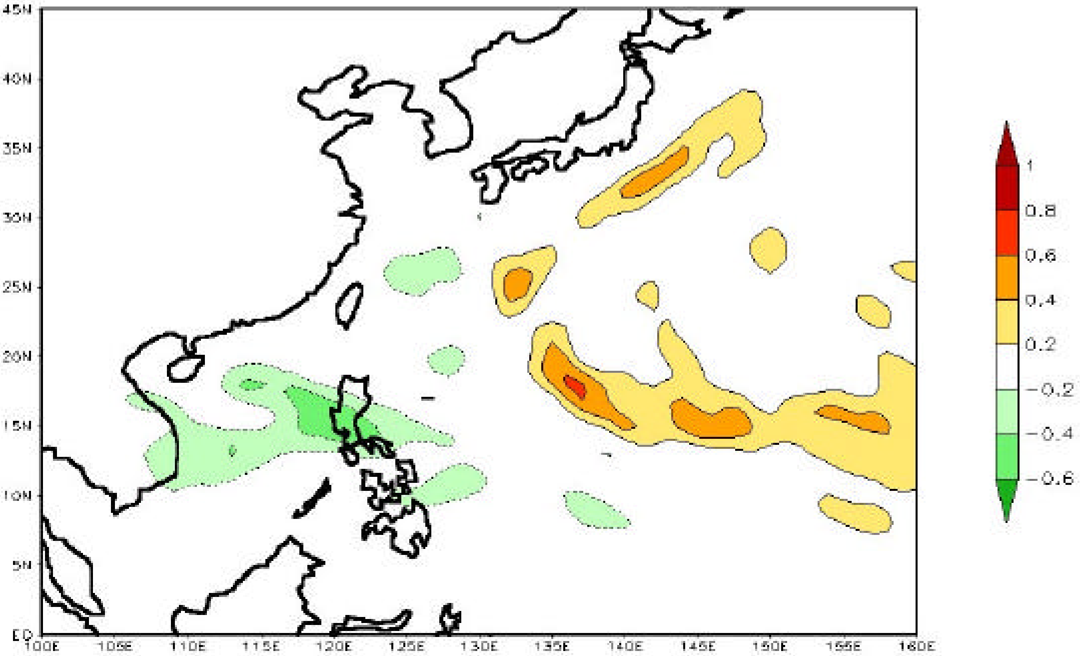
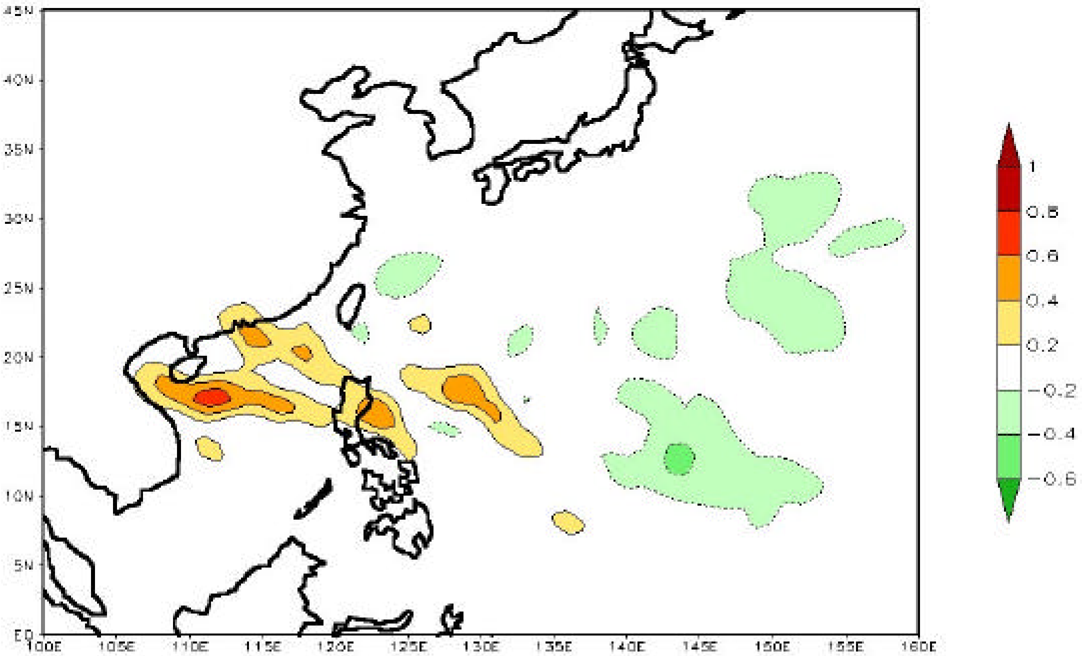


Fig. 5.1. Spectral analysis of the number of tropical cyclones affecting Hong Kong in a year, 1946-2001.



(a) El Niño years



(b) La Niña years

Fig. 5.2. Tropical cyclone track density in the late season (September to November) relative to neutral years for (a) El Niño and (b) La Niña years.

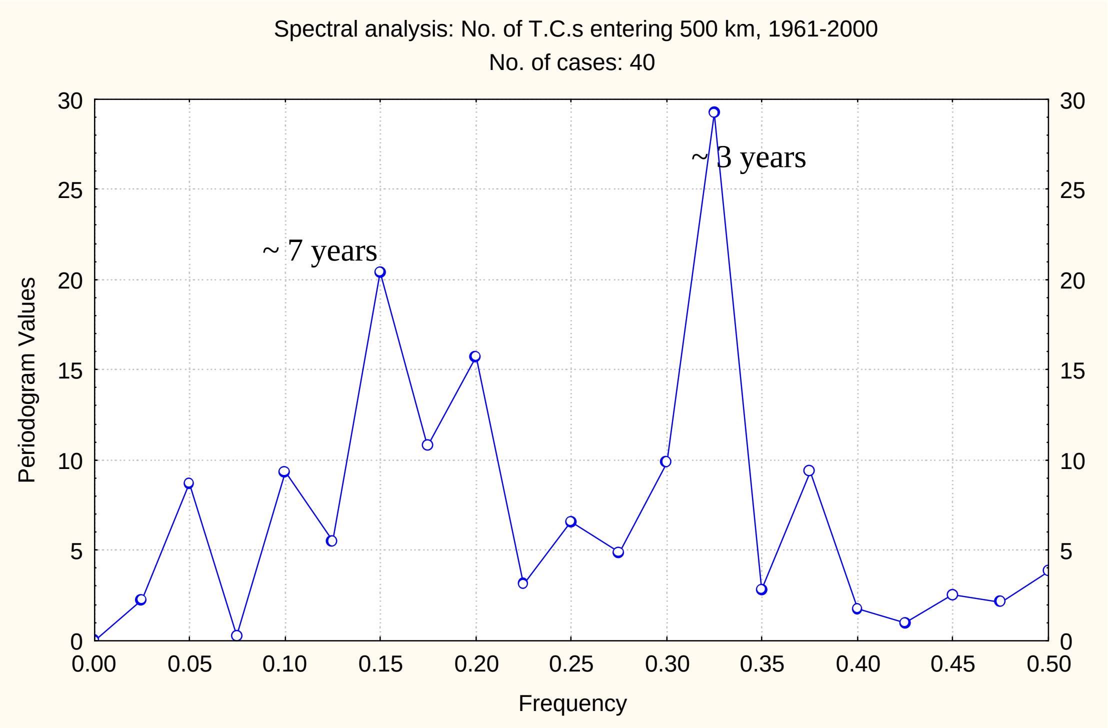


Fig 5.3. Spectral analysis of the number of tropical cyclones entering within 500 km of Hong Kong in a year.

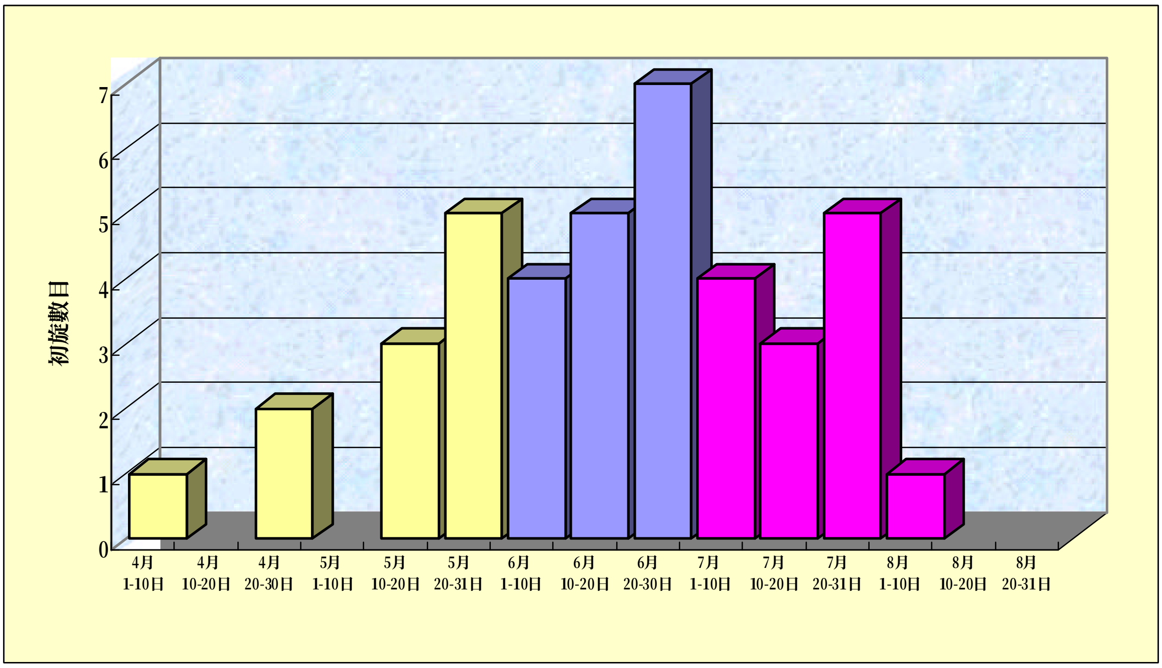


Fig. 6.1. Distribution of the time of onset of the tropical cyclone season in Hong Kong, 1961-2000.

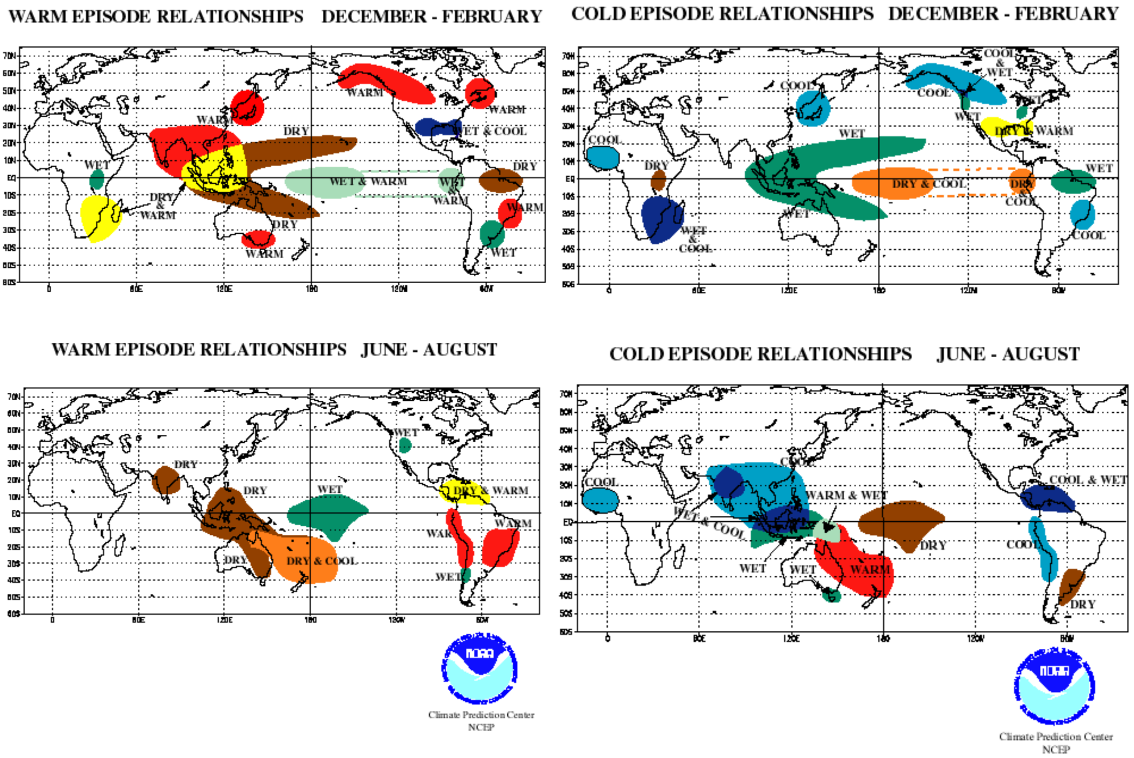


Fig. 7.1. Typical global impacts of El Niño and La Niña events in winter and summer. (Source: NCEP's webpage).

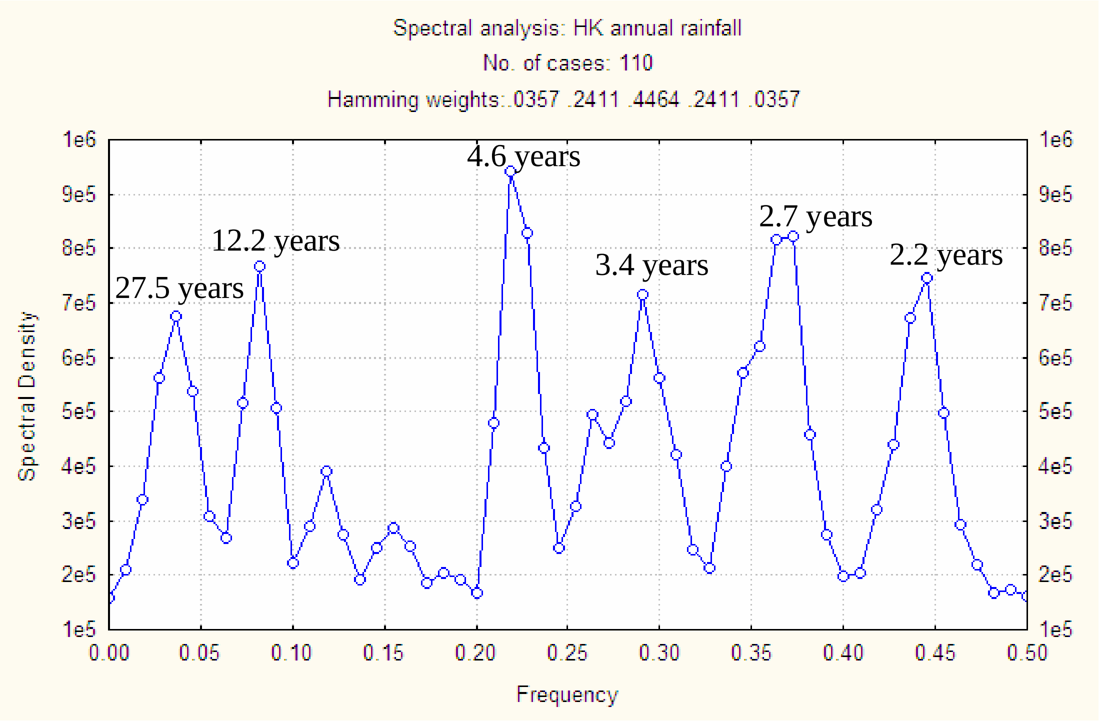


Fig. 7.2. Spectral analysis of annual rainfall in Hong Kong, 1884-2001.

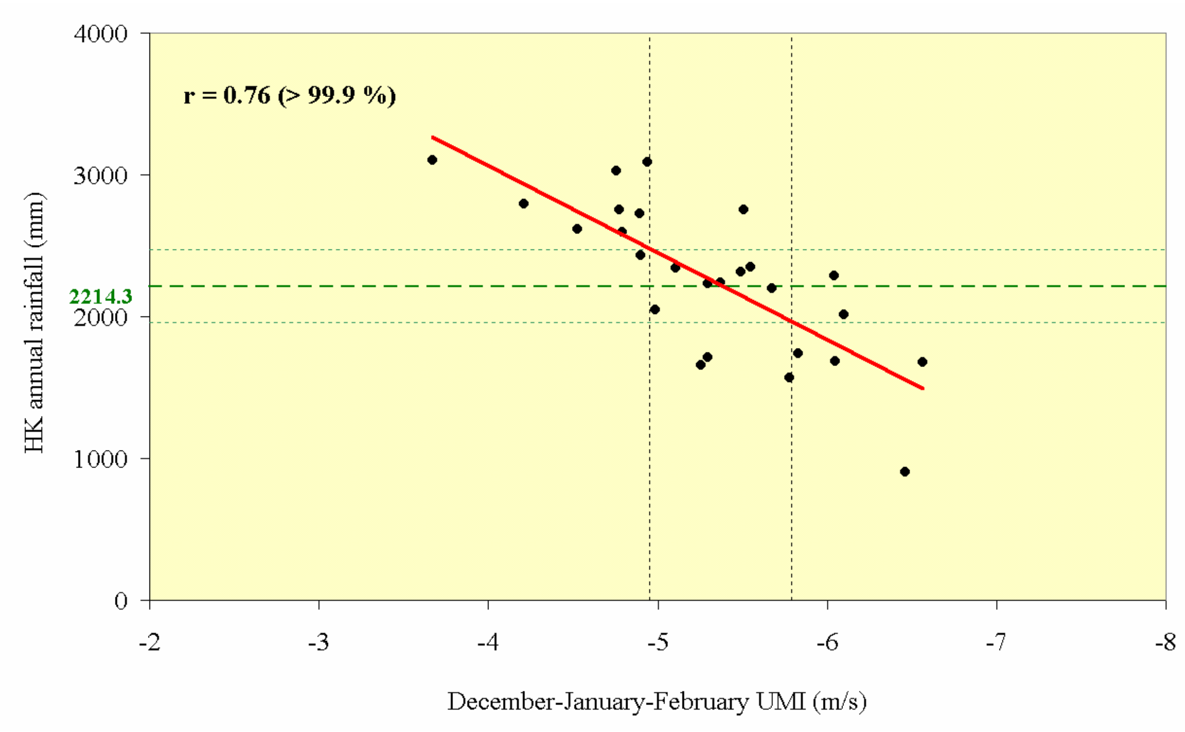
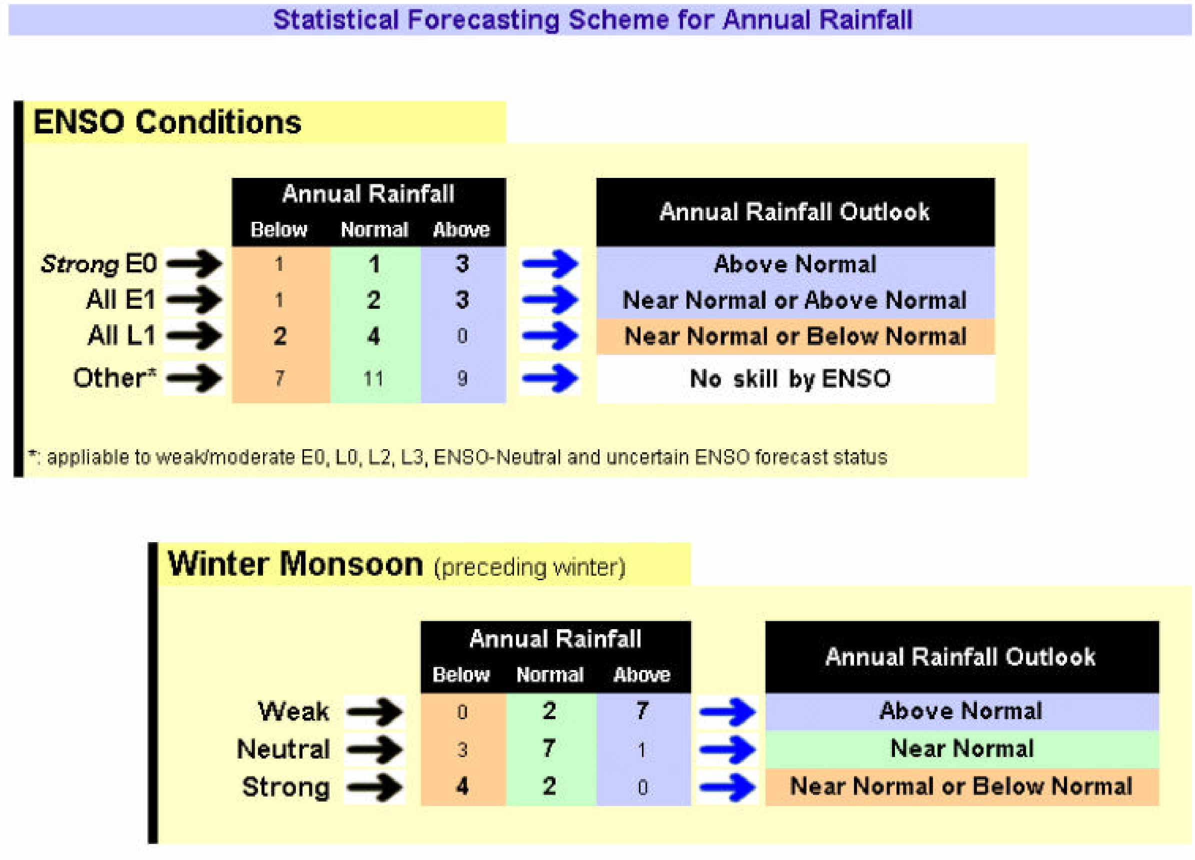


Fig. 7.3. Correlation between annual rainfall in Hong Kong and the winter Unified Monsoon Index (UMI). Years with strong El Niño onset, years immediately following El Niño onset, and years immediately following La Niña onset are excluded.



Statistical Forecasting Scheme for Annual Rainfall

ENSO Conditions

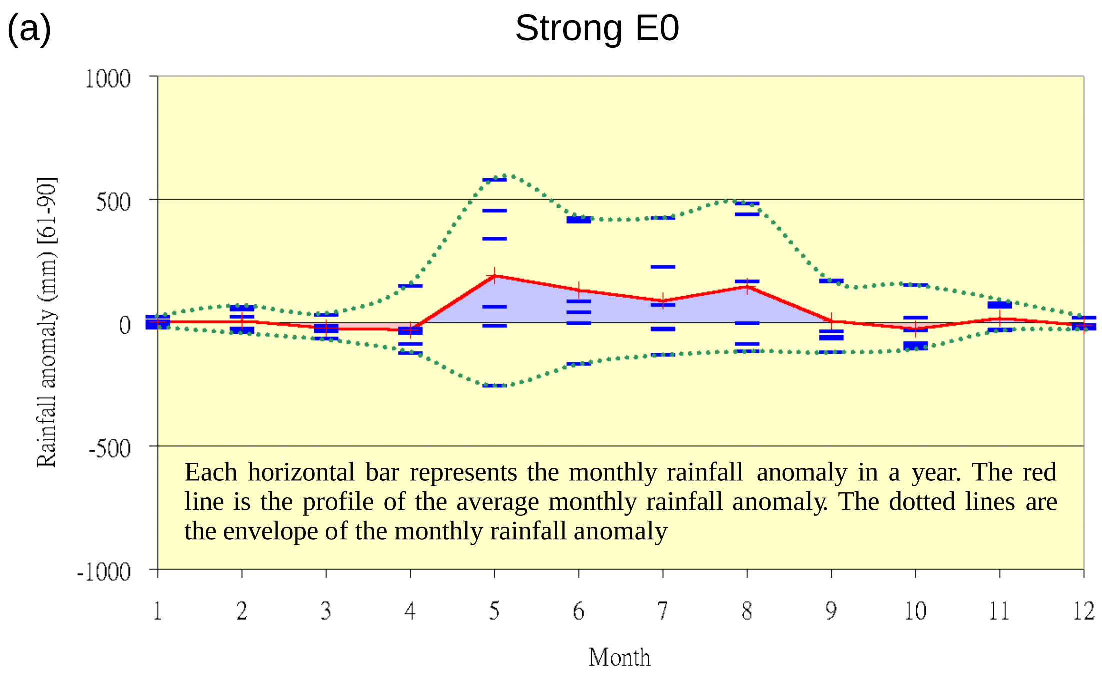
	Annual Rainfall Below	Annual Rainfall Normal	Annual Rainfall Above		Annual Rainfall Outlook
Strong E0 →	1	1	3	→	Above Normal
All E1 →	1	2	3	→	Near Normal or Above Normal
All L1 →	2	4	0	→	Near Normal or Below Normal
Other* →	7	11	9	→	No skill by ENSO

*: appliable to weak/moderate E0, L0, L2, L3, ENSO-Neutral and uncertain ENSO forecast status

Winter Monsoon (preceding winter)

	Annual Rainfall Below	Annual Rainfall Normal	Annual Rainfall Above		Annual Rainfall Outlook
Weak →	0	2	7	→	Above Normal
Neutral →	3	7	1	→	Near Normal
Strong →	4	2	0	→	Near Normal or Below Normal

Fig. 7.4. Conceptual model for the forecasting of annual rainfall in Hong Kong.



Each horizontal bar represents the monthly rainfall anomaly in a year. The red line is the profile of the average monthly rainfall anomaly. The dotted lines are the envelope of the monthly rainfall anomaly

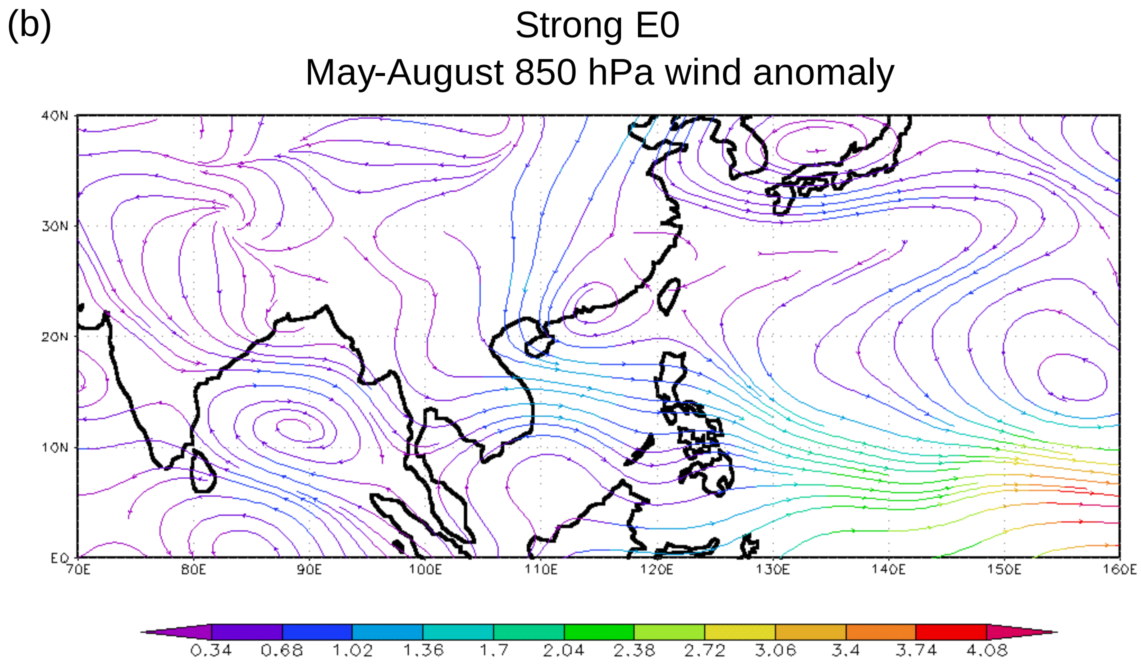
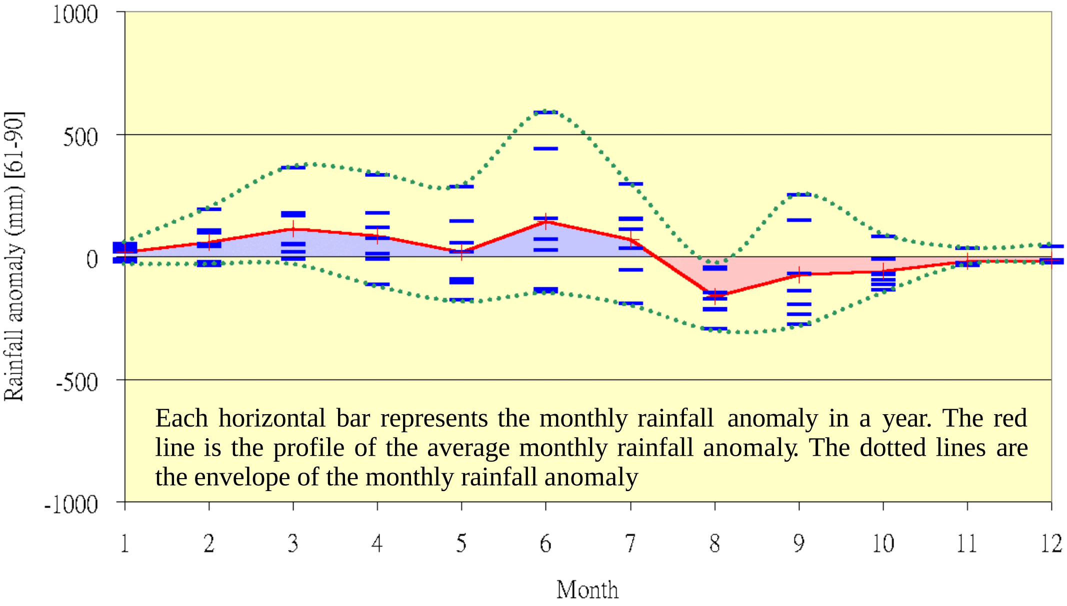


Fig. 7.5. Conditions in strong El Niño onset years [E0]: (a) monthly rainfall anomalies in Hong Kong, (b) 850 hPa wind anomalies during May-August based on NCEP's reanalysis data.



(a) E1

Each horizontal bar represents the monthly rainfall anomaly in a year. The red line is the profile of the average monthly rainfall anomaly. The dotted lines are the envelope of the monthly rainfall anomaly

(b) E1

February-July 850 hPa wind anomaly

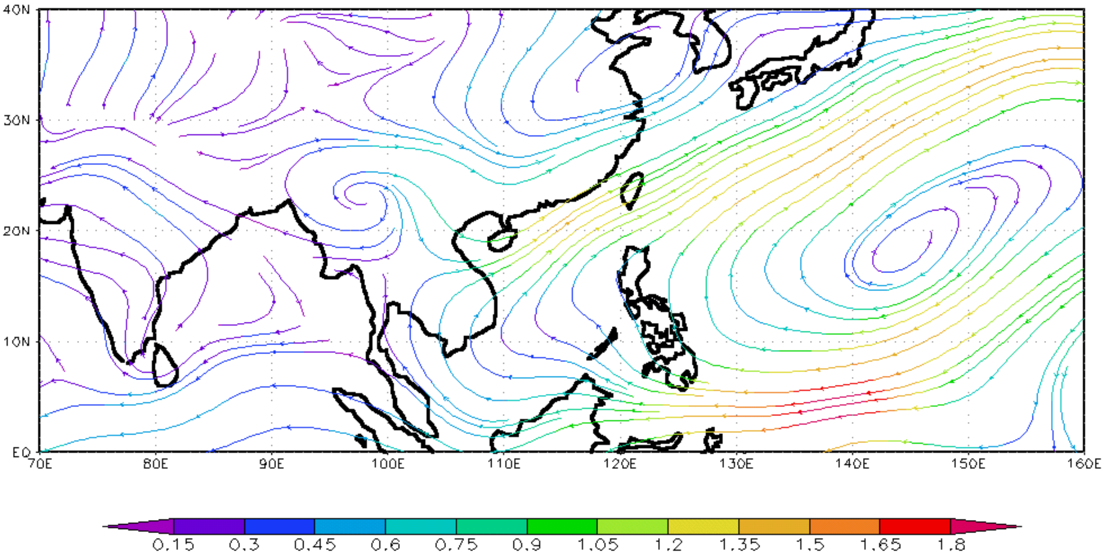
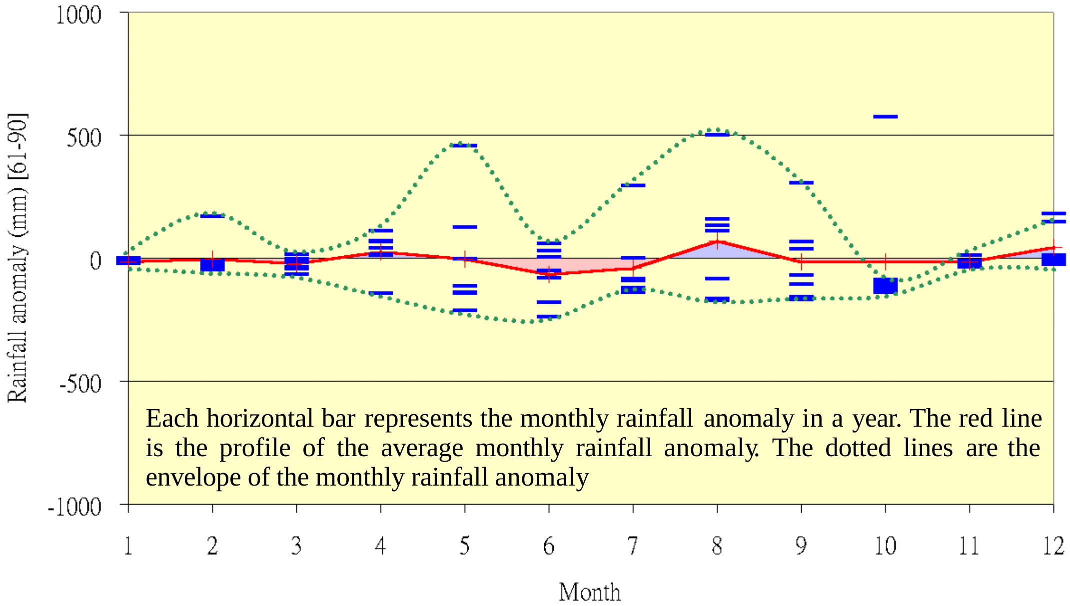


Fig. 7.6. Conditions in years immediately following El Niño onset years [E1]: (a) monthly rainfall anomalies in Hong Kong, (b) 850 hPa wind anomalies during February-July based on NCEP's reanalysis data.

(a) L1



Each horizontal bar represents the monthly rainfall anomaly in a year. The red line is the profile of the average monthly rainfall anomaly. The dotted lines are the envelope of the monthly rainfall anomaly

(b) L1
June-July 850 hPa wind anomaly

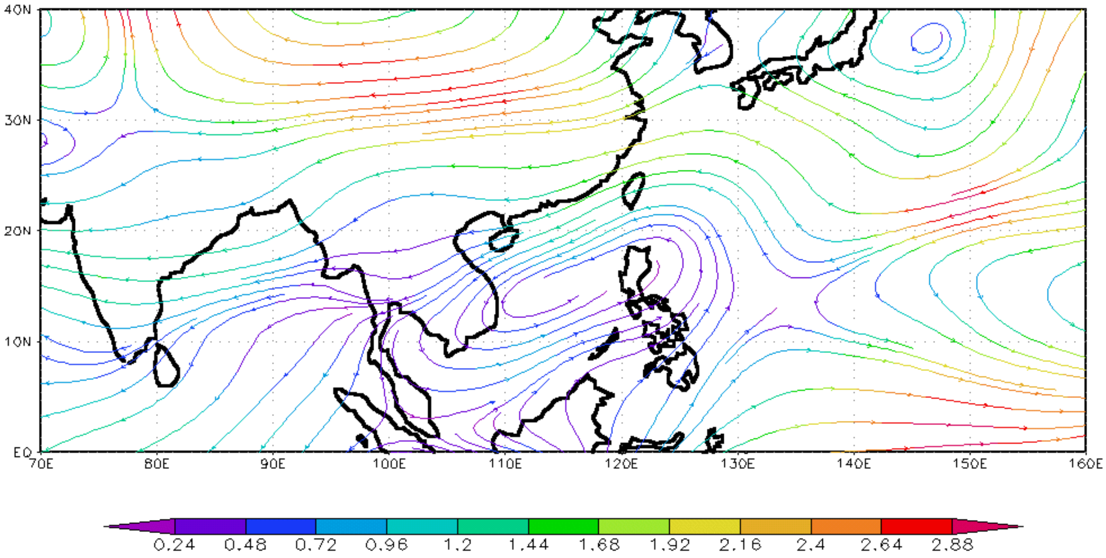
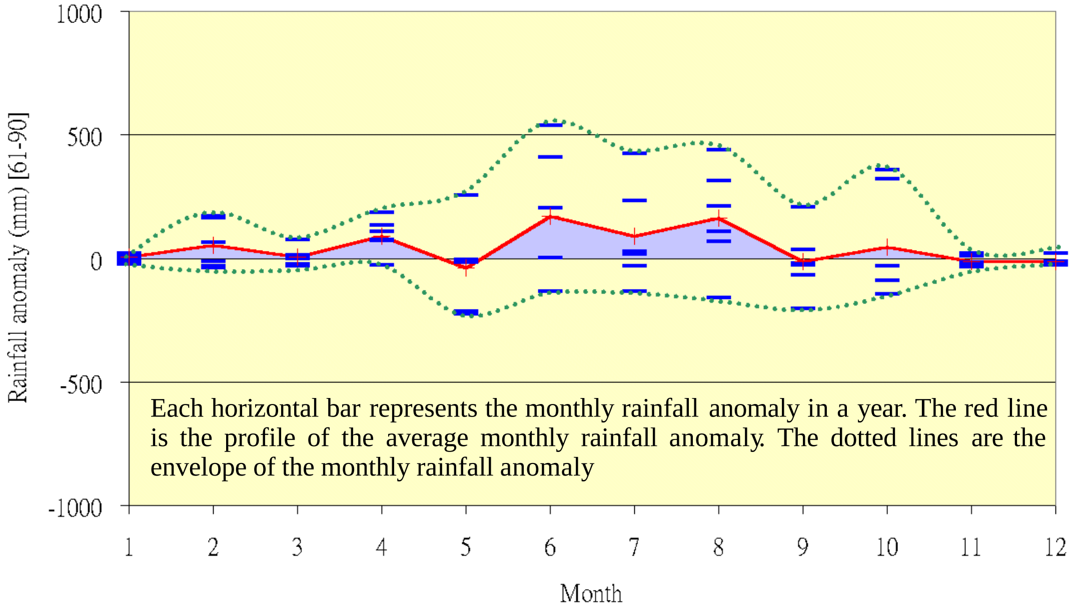
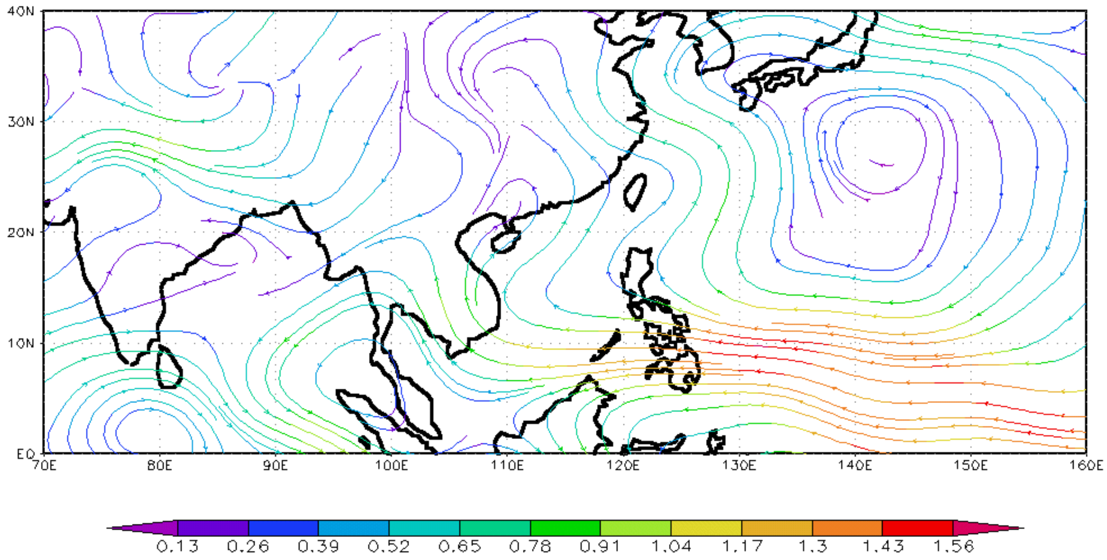


Fig. 7.7. Conditions in year immediately following La Niña onset years [L1]: (a) monthly rainfall anomaly in Hong Kong, (b) 850 hPa wind anomalies during June-July based on NCEP's reanalysis data.



(a) Weak winter monsoon (excluding strong E0, E1 and L1)

Each horizontal bar represents the monthly rainfall anomaly in a year. The red line is the profile of the average monthly rainfall anomaly. The dotted lines are the envelope of the monthly rainfall anomaly



(b) Weak winter monsoon (excluding strong E0, E1 and L1)
June-August 850 hPa wind anomaly

Fig. 7.8. Conditions in weak winter monsoon years excluding strong E0, all E1 and all L1: (a) monthly rainfall anomalies in Hong Kong, (b) 850 hPa wind anomalies during June-August based on NCEP's reanalysis data.

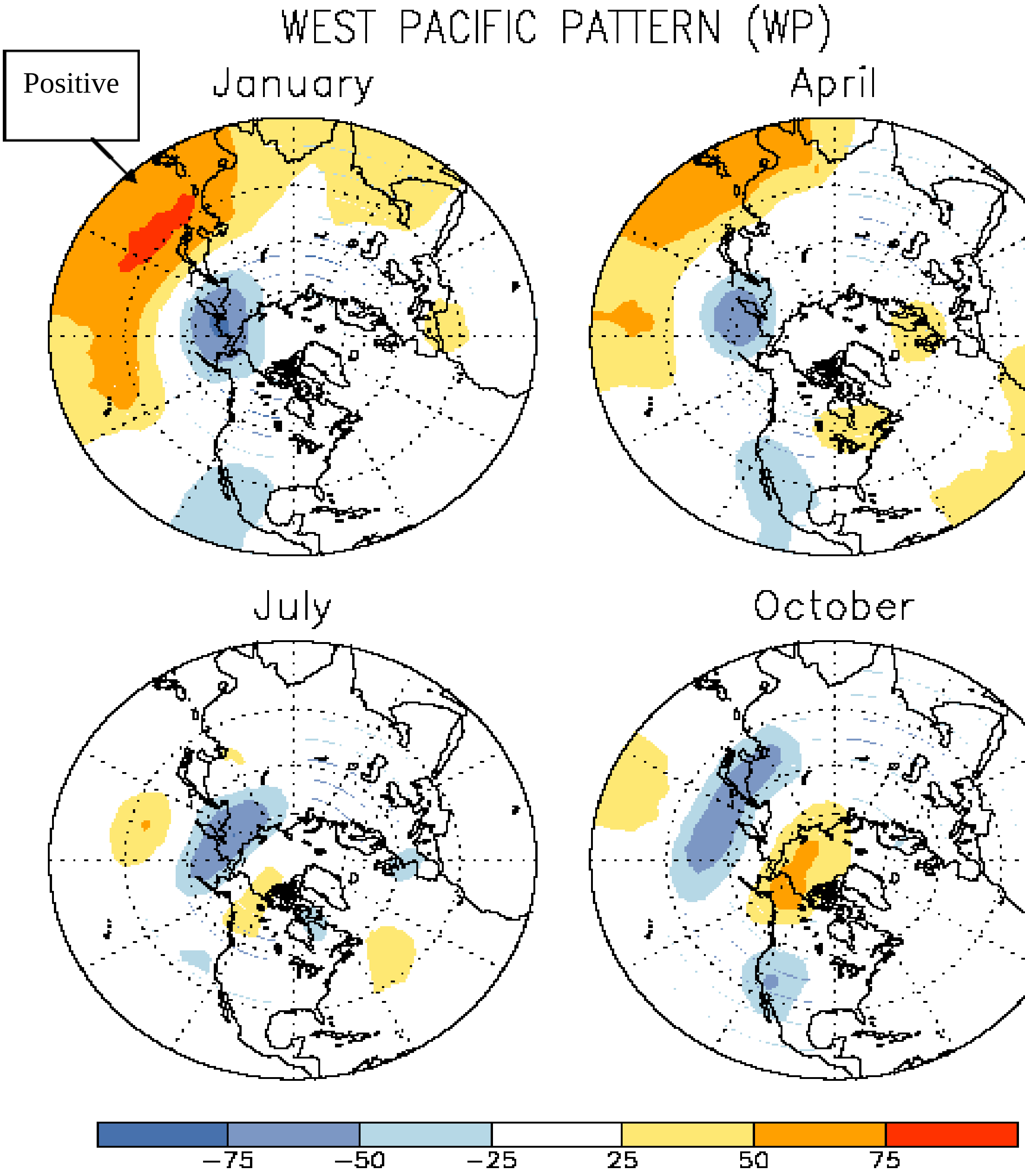


Fig. 9.1. Positive phase of the West Pacific (WP) pattern. The plotted values are 700 hPa geopotential height anomalies. (Source: CPC' s webpage).

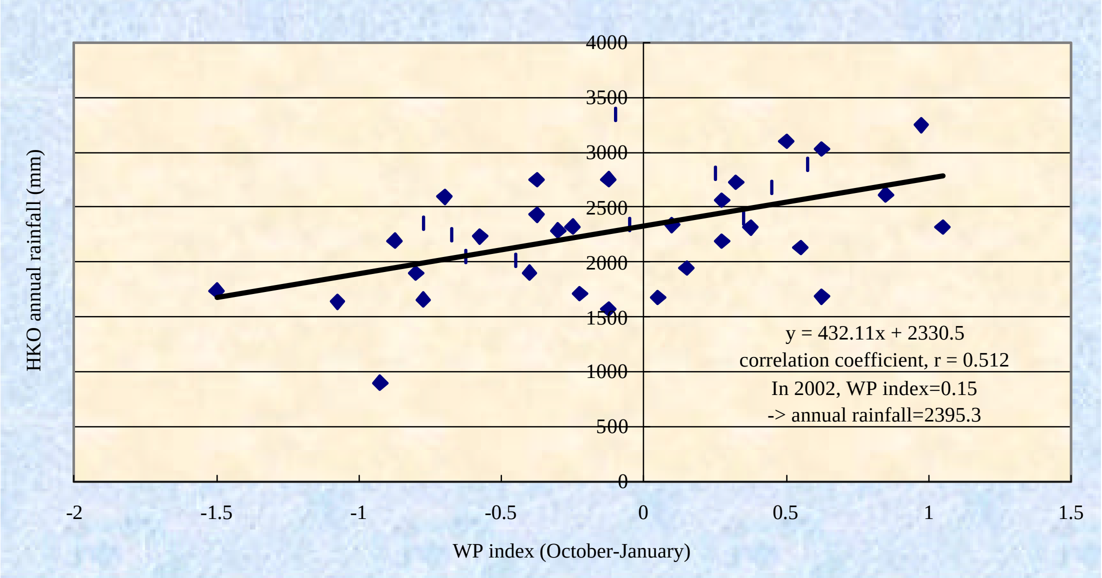


Fig. 9.2. Scatter diagram of the WP index in the preceding October -January and annual rainfall in Hong Kong, 1961-2000.

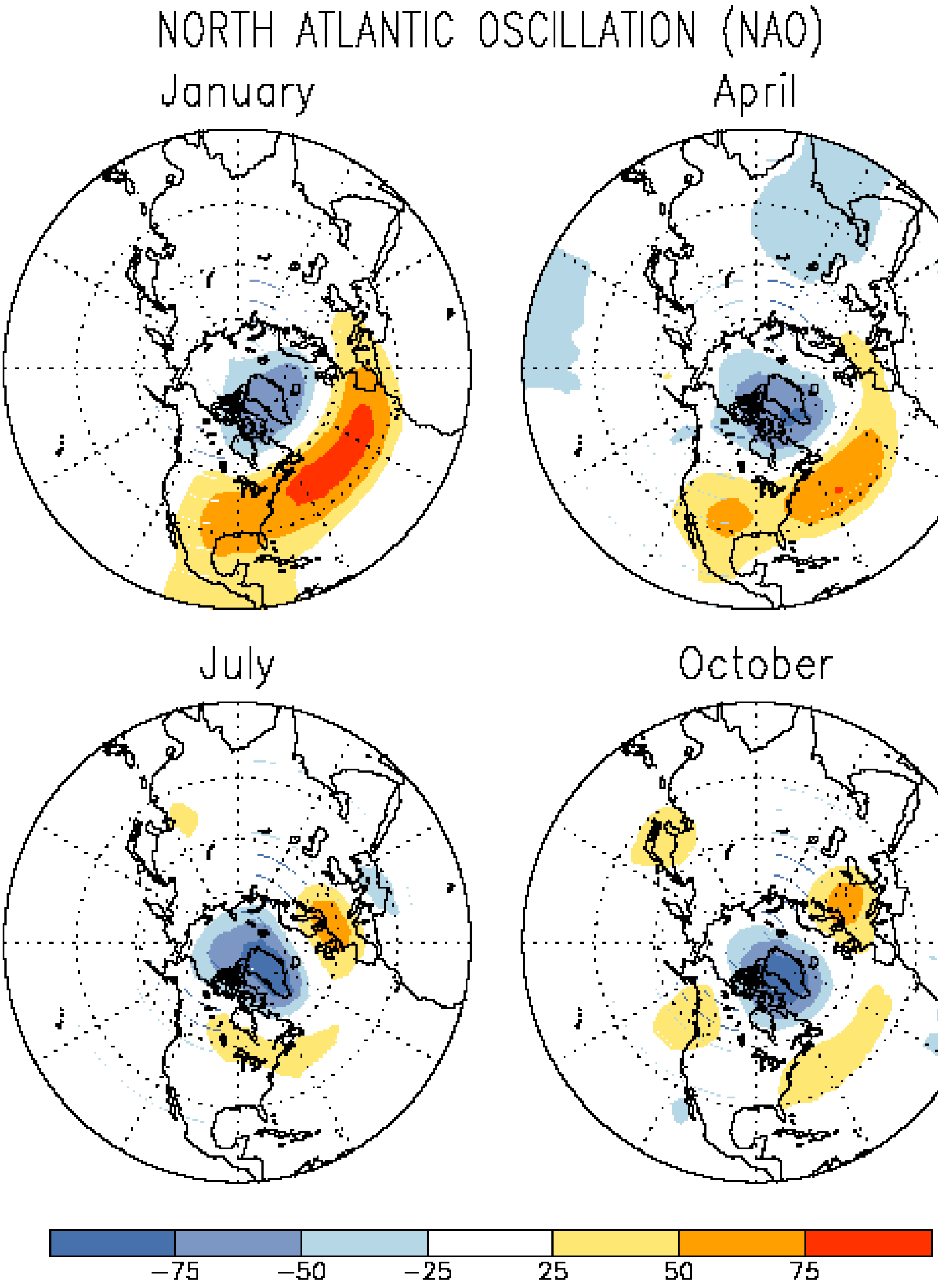


Fig. 9.3. Positive phase of the North Atlantic Oscillation (NAO) pattern. The plotted values are 700 hPa geopotential height anomalies. (Source: CPC' s webpage).

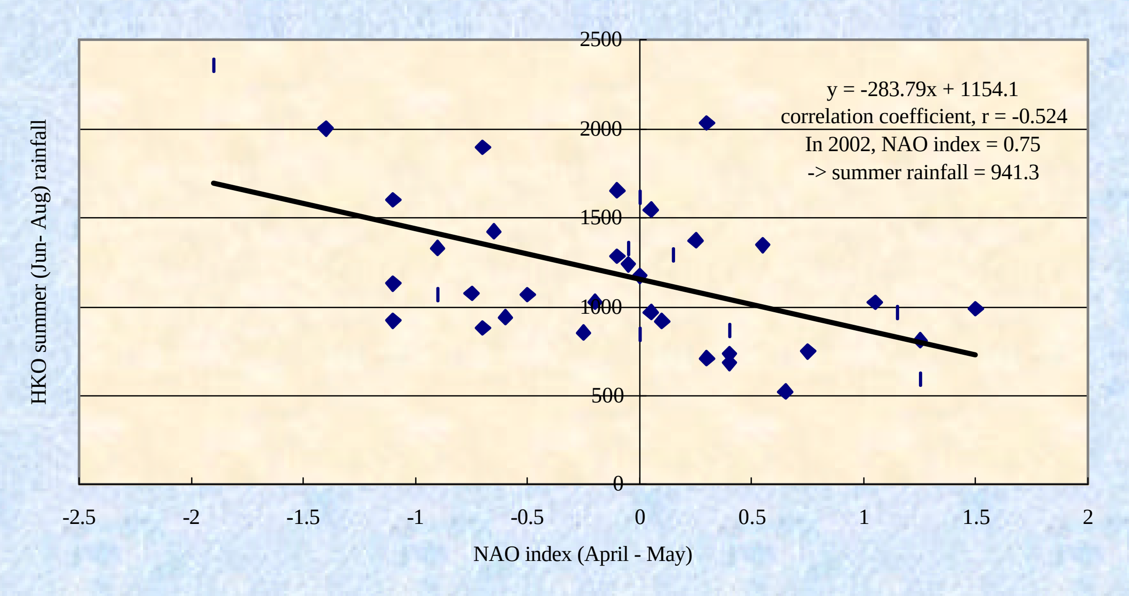


Fig. 9.4. Scatter diagram of NAO index (April-May) and summer (June-August) rainfall in Hong Kong, 1961-2000.

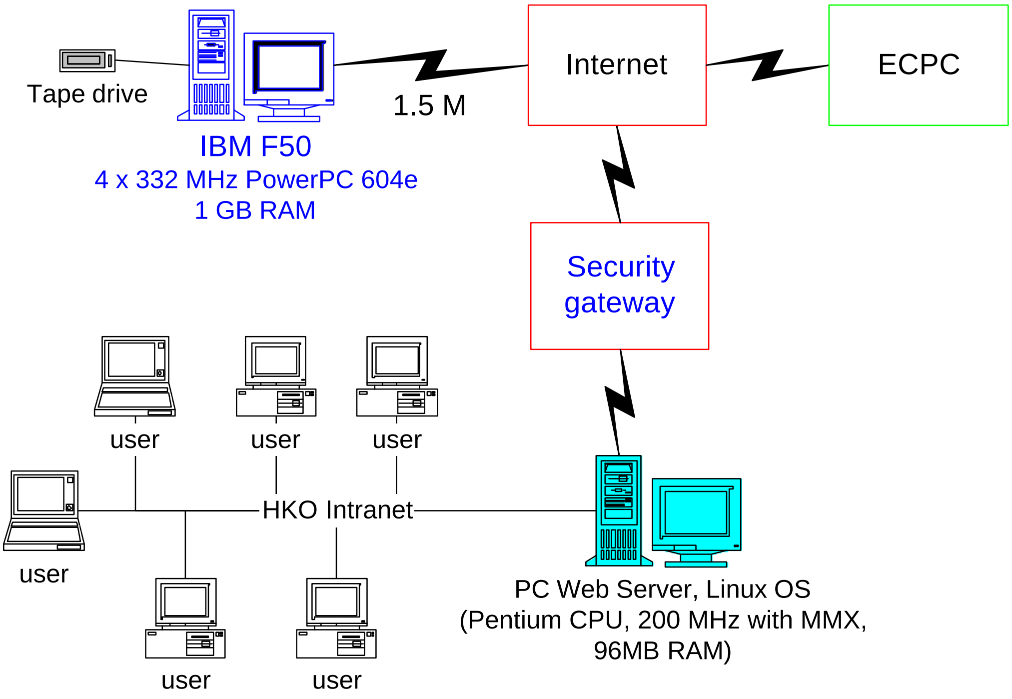


Fig. 10.1. Hardware set up for running the regional climate model.

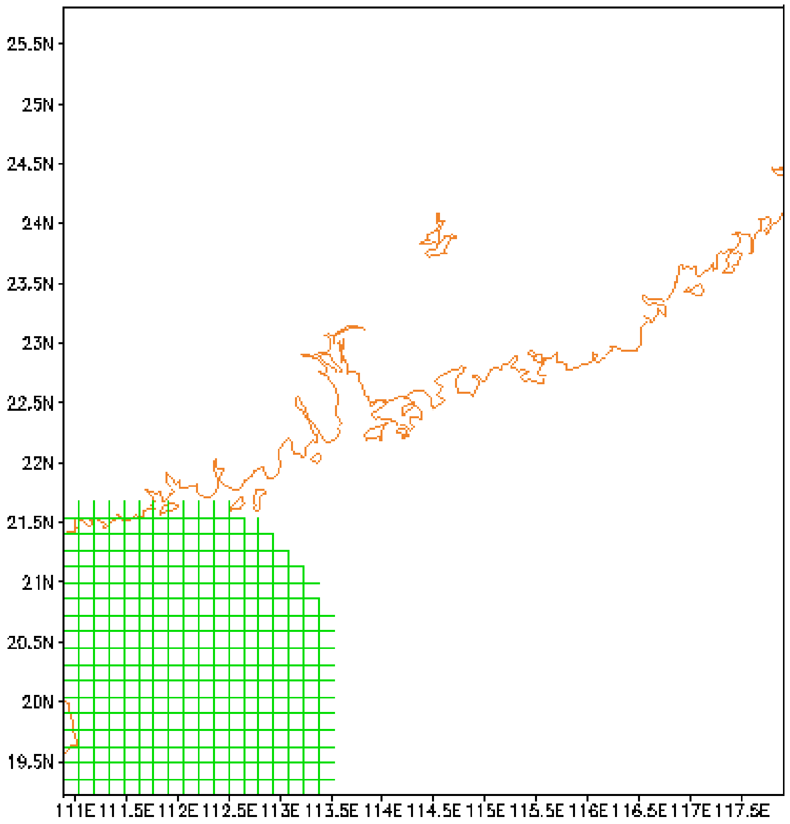


Fig. 10.2. The inner domain of the regional climate model centred on Hong Kong. The mesh at the lower left corner shows the horizontal grid.

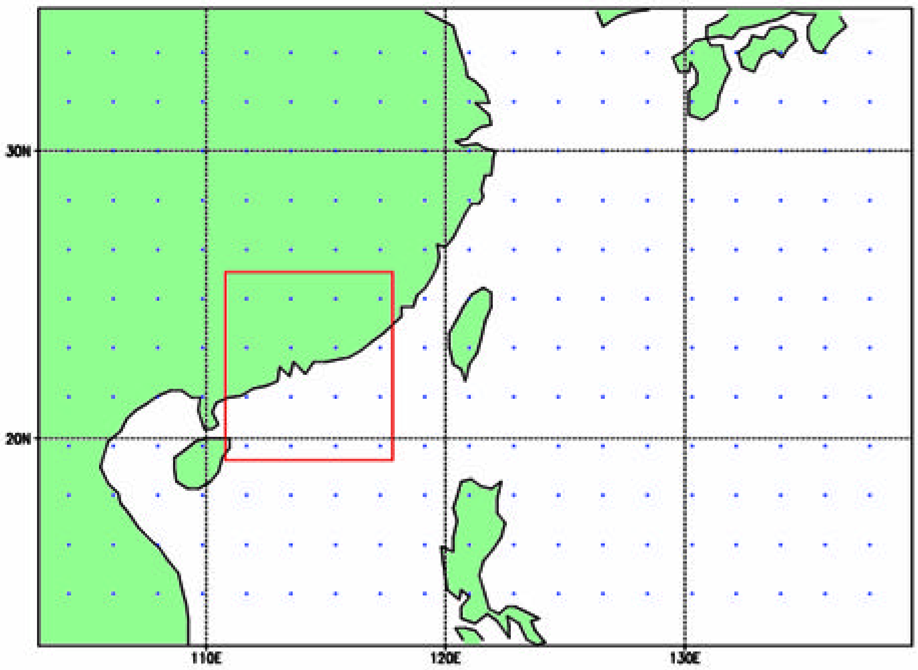


Fig. 10.3. The outer domain of the regional climate model.

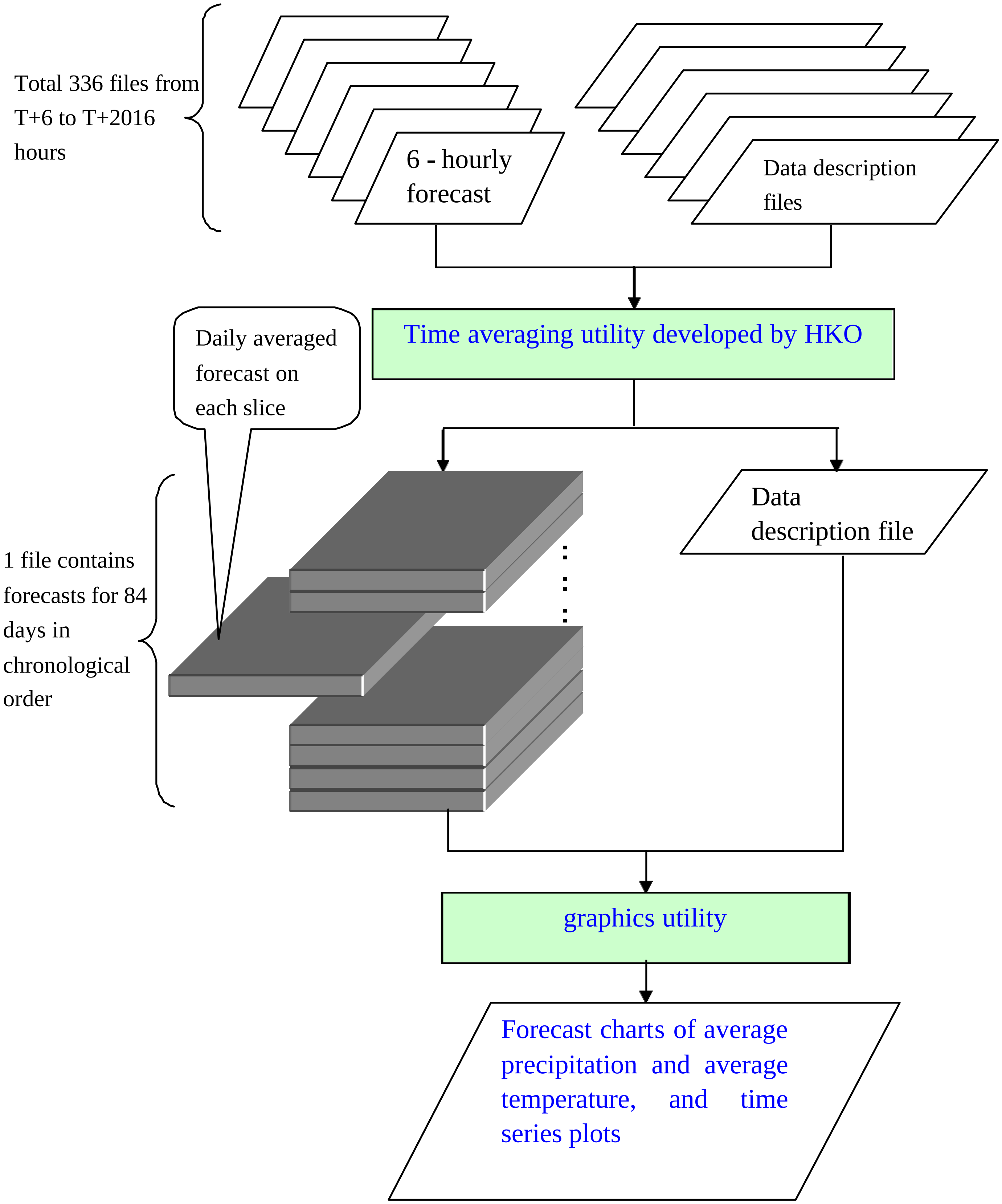


Fig. 10.4. Schematic of the time averaging facility.

Tables

Table 5.1. Number of tropical cyclones (TCs) affecting Hong Kong (i.e. necessitating the issuance of local tropical cyclone signals) between 1961 and 2001 under different ENSO conditions.

E0 (El Niño onset)			**E1** (year immediately following El Niño onset)			**Neutral**		
year	strength	TC No.	year	strength	TC No.	year	strength	TC No.
1963		4	1966		6	1961		6
1965		6	1969		4	1962		4
1968		6	1983	strong	7	1977		8
1972	strong	5	1987	strong	5	1978		8
1976		5	1992	strong	5	1980		10
1979		6	1998	strong	5	1981		5
1982	strong	5				1990		6
1986	strong	4				2001		6
1991	strong	6						
1993		9						
1994		4						
1997	strong	2						
	mean	**5.2**			**5.3**			**6.6**
standard deviation		**1.6**			**0.9**			**1.8**

L0 (La Niña onset)			**L1** (year following La Niña onset)			**L2** (second year following La Niña onset)		
year	strength	TC No.	year	strength	TC No.	year	strength	TC No.
1964		10	1971	strong	9	1975	strong	7
1967		8	1974	strong	11	2000	strong	7
1970	strong	6	1985		5			
1973	strong	9	1989	strong	7			
1984		5	1996		7			
1988	strong	6	1999	strong	8			
1995		8						
	mean	**7.4**			**7.8**			**7.0**
standard deviation		**1.7**			**1.9**			**0.0**

Table 5.2. Number of tropical cyclones (TCs) affecting Hong Kong (i.e. necessitating the issuance of local tropical cyclone signals) between 1961 and 2001 categorized by May to October QBO phases.

	TC No.		
QBO	<=5	6-7	>=8
East	**7**	**9**	1
West	3	4	6
East to West	4	0	1
West to East	1	2	3

Table 5.3. Number of tropical cyclones entering within a given distance of Hong Kong.

Year	No. coming within a distance of r (km) of Hong Kong					**No. with local tropical cyclone signals.**
	r=400	**r=500**	r=600	r=700	r=800	
1961	8	**8**	13	14	15	6
1962	2	**4**	8	10	12	4
1963	3	**5**	6	10	11	4
1964	6	**7**	10	10	10	10
1965	6	**6**	7	8	8	6
1966	5	**5**	7	10	10	6
1967	9	**11**	11	12	12	8
1968	5	**7**	7	7	8	6
1969	2	**2**	4	6	6	4
1970	5	**6**	9	9	10	6
1971	4	**6**	10	14	15	9
1972	5	**5**	6	6	6	5
1973	8	**9**	11	12	13	9
1974	9	**11**	13	13	14	11
1975	6	**8**	8	9	9	7
1976	5	**6**	6	6	7	5
1977	3	**7**	9	10	10	8
1978	4	**6**	9	10	10	8
1979	5	**6**	8	9	9	6
1980	8	**9**	11	13	13	10
1981	5	**5**	8	10	10	5
1982	4	**4**	6	7	7	5
1983	5	**8**	8	8	9	7
1984	5	**6**	7	7	8	5
1985	5	**7**	9	10	10	5
1986	5	**5**	6	6	7	4
1987	3	**4**	4	5	6	5
1988	4	**6**	8	8	8	6
1989	3	**6**	8	9	9	7
1990	5	**6**	7	9	9	6
1991	5	**5**	7	9	10	6
1992	4	**5**	5	7	7	5
1993	7	**7**	9	9	9	9
1994	7	**8**	11	13	13	4
1995	6	**9**	10	11	11	8
1996	4	**6**	10	10	10	7
1997	3	**3**	3	4	4	2
1998	4	**5**	5	7	8	5
1999	8	**9**	10	10	10	8
2000	3	**5**	7	9	9	7
2001	5	**5**	6	9	11	6
1961-1990 mean	5.1	**6.4**	8.1	9.2	9.7	**6.4**

Table 6.1. Joint probabilities of early onset (May or before) of the tropical cyclone season in Hong Kong, based on 1961-2001 data.

ENSO status	**QBO phase in the first half of the year**				
	East	West	East to West	West to East	Total
El Niño	**0/5**	**0/4**	**0/0**	**0/3**	**0/12**
La Niña	1/3	**4/4**	0/1	0/0	5/8
El Niño to La Niña	0/2	0/2	0/0	0/0	0/4
Normal	0/5	4/7	2/2	0/3	6/17
Total	1/15	8/17	2/3	0/6	11/41

Table 6.2. Joint probabilities of the late onset (July or after) of the tropical cyclone season in Hong Kong, based on 1961-2001 data.

ENSO status	**QBO phase in the first half of the year**				
	East	West	East to West	West to East	Total
El Niño	0/5	3/4	0/0	2/3	5/12
La Niña	**0/3**	**0/4**	**0/1**	**0/0**	**0/8**
El Niño to La Niña	**2/2**	**2/2**	**0/0**	**0/0**	**4/4**
Normal	2/5	0/7	0/2	2/3	4/17
Total	4/15	5/17	0/3	4/6	13/41

Table 6.3. Joint probabilities of the normal onset (June) of the tropical cyclone season in Hong Kong, based on 1961-2001 data.

ENSO status	**QBO phase in the first half of the year**				
	East	West	East to West	West to East	Total
El Niño	**5/5**	1/4	0/0	1/3	7/12
La Niña	2/3	0/4	1/1	0/0	3/8
El Niño to La Niña	0/2	0/2	0/0	0/0	0/4
Normal	3/5	3/17	0/2	1/3	7/17
Total	10/15	4/17	1/3	2/6	17/41

Table 7.1. The ten wettest years in Hong Kong since 1947. E0: El Niño onset year, E1: year immediately following El Niño onset. L0: La Niña onset year, L1 and L2: respectively the first and second years following La Niña onset.

Year	Rainfall (mm)	**ENSO status**
1997	3343.0	E0 (strong)
1982	3247.5	E0 (strong)
1973	3100.4	L0 (following strong E0)
2001	3091.8	
1975	3028.7	L2
1957	2950.3	E0 (strong)
1983	2893.8	E1 (strong)
1972	2807.3	E0 (strong)
1959	2797.4	
1995	2754.4	L0 (following weak E0)

Table 8.1. Probability of 4-5, 5-6 and 4-6 tropical cyclones entering within a given distance of Hong Kong in strong El Niño onset years.

Year	No. (N) coming within a distance of r (km) of Hong Kong					**No. requiring signals**
	r=400	**r=500**	r=600	r=700	r=800	
1972	5	5	6	6	6	5
1982	4	4	6	7	7	5
1986	5	5	6	6	7	4
1991	5	5	7	9	10	6
1997	3	3	3	4	4	2
mean	4.4	4.4	5.6	6.4	6.8	4.4
Probability (N=4-5)	4/5 (80%)	4/5 (80%)	0/5 (0%)	1/5 (20%)	1/5 (20%)	3/5 (60%)
Probability (N=5-6)	3/5 (60%)	**3/5 (60%)**	3/5 (60%)	2/5 (40%)	1/5 (20%)	**3/5 (60%)**
Probability (N=4-6)	4/5 (80%)	4/5 (80%)	3/5 (60%)	3/5 (60%)	2/5 (40%)	4/5 (80%)

Table 8.2. Probability of 4-5, 5-6 and 4-6 tropical cyclones entering within a given distance of Hong Kong in El Niño onset years excluding strong El Niño onset years.

Year	No. (N) coming within a distance of r (km) of Hong Kong					No. requiring signals
	r=400	**r=500**	r=600	r=700	r=800	
1963	3	5	6	10	11	4
1965	6	6	7	8	8	6
1968	5	7	7	7	8	6
1976	5	6	6	6	7	5
1979	5	6	8	9	9	6
1993	7	7	9	9	9	9
1994	7	8	11	13	13	4
mean	5.43	6.43	7.71	8.86	9.29	5.71
Probability (N=4-5)	3/7 (42.86%)	1/7 (14.29%)	0/7 (0%)	0/7 (0%)	0/7 (0%)	3/7 (42.86%)
Probability (N=5-6)	4/7 (57.14%)	**4/7 (57.14%)**	2/7 (28.57%)	1/7 (14.29%)	0/7 (0%)	**4/7 (57.14%)**
Probability (N=4-6)	4/7 (57.14%)	4/7 (57.14%)	2/7 (28.57%)	1/7 (14.29%)	0/7 (0%)	6/7 (85.71%)

Table 8.3. Probability of 4-5, 5-6 and 4-6 tropical cyclones entering within a given distance of Hong Kong in neutral years.

Year	No. (N) coming within a distance r (km) of Hong Kong					**No. requiring signals**
	r=400	**r=500**	r=600	r=700	r=800	
1961	8	8	13	14	15	6
1962	2	4	8	10	12	4
1977	3	7	9	10	10	8
1978	4	6	9	10	10	8
1980	8	9	11	13	13	10
1981	5	5	8	10	10	5
1990	5	6	7	9	9	6
2001	5	5	6	9	11	6
mean	5.0	6.3	8.9	10.6	11.3	6.6
Probability (N=4-5)	4/8 (50%)	3/8 (37.5%)	0/8 (0%)	0/8 (0%)	0/8 (0%)	2/8 (25%)
Probability (N=5-6)	3/8 (37.5%)	**4/8 (50%)**	1/8 (12.5%)	0/8 (0%)	0/8 (0%)	**4/8 (50%)**
Probability (N=4-6)	4/8 (50%)	5/8 (62.5%)	1/8 (12.5%)	0/8 (0%)	0/8 (0%)	5/8 (62.5%)

Table 9.1. Contingency table of the WP index (October-January) and annual rainfall at the Hong Kong Observatory, 1961-2000.

WP index (October –January)	**HKO annual rainfall**			Total
	Below normal	Near normal	Above normal	
	(<1958 mm)	(1958-2470 mm)	(>2470 mm)	
Below normal (<-0.42)	5	6	**1**	12
Near normal (-0.42 to 0.22)	5	5	3	13
Above normal (>0.22)	**1**	5	9	15
Total	11	16	13	40

Table 9.2. Contingency table of the NAO index (April-May) and summer (June-August) rainfall at the Hong Kong Observatory, 1961-2000

NAO (April - May)	**HKO summer (June – August) rainfall**			Total
	Below normal	Near normal	Above normal	
	(<918mm)	(918 -1265 mm)	(>1265 mm)	
Below normal (<-0.38)	**1**	6	6	13
Near normal (-0.38 to 0.28)	2	5	7	14
Above normal (>0.28)	8	3	**2**	13
Total	11	14	15	40

Table 10.1. Ensemble rainfall forecasts for Hong Kong for May and June, 1998 to 2001, based on Hong Kong Observatory's regional climate model.

(a) May and June **1998**

Model run start date	Rainfall forecast (mm/day)	
	May	June
19980404	3.9	30.6
19980411	17.2	36.5
19980418	8	26.8
19980425	3.6	18.6
Ensemble mean	**8.2**	**28.1**
Observed rainfall	10.8	27.2

(b) May and June **1999**

Model run start date	Rainfall forecast (mm/day)	
	May	June
19990403	21.1	33.4
19990410	18.6	20.5
19990417	16.4	25.2
19990424	15.5	43.7
Ensemble mean	**17.9**	**30.7**
Observed rainfall	5.7	6.6

(c) May and June **2000**

Model run start date	Rainfall forecast (mm/day)	
	May	June
20000401	8.6	29.3
20000408	15.5	36.0
20000415	18.7	31.3
20000422	7.3	27.2
20000429	4.6	38.8
Ensemble mean	**10.9**	**32.5**
Observed rainfall	6.7	14.8

(d) May and June **2001**

Model run start date	Rainfall forecast (mm/day)	
	May	June
20010407	4.2	15.1
20010414	3.6	26.5
20010421	8.2	15.4
20010428	4.8	19.5
Ensemble mean	**5.2**	**19.1**
Observed rainfall	5.2	36.1

Annex 1

Use of Probability Forecasts and Cost-Loss Analysis

If you know your cost to loss ratio, then probability forecasts would let you work out the thresholds for taking action.

2. Let say you have a business that is sensitive to a certain kind of climate anomaly. This might be having to pay out compensation for wind damage by tropical cyclones above the normal number for tropical cyclones.

3. Also, let say that the cost **C** of taking action to prevent wind damage is HK$ 1 000, the loss **L** if no action is taken is HK$5 000, and the probability of having above normal number of tropical cyclones is forecast to be 60%.

4. Knowing this probability you can work out the expected gain or loss of taking action against taking no action. For the given HK$1 000 cost and HK$5 000 loss, this turns out to be an expected gain of $2000 for action, against an expected loss of $3000 for no action.

5. The expected gain (or loss) for taking action is equal to the gain (or loss) for taking no action when P = C/2L, the break-even point. You can expect to come out ahead by taking action when the probability P exceeds C/2L.

6. To illustrate, if the ratio of your cost to loss is 1 to 5, the break-even point is P= 1/(2x5) or 10%. You will come out ahead by taking protection even if the forecast probability is as small as 20%.

7. If the ratio of your cost to loss is 1, then the break-even point is when P = 1/(2x1) or 50%. You can expect to benefit by taking action only when the forecast has more than an even chance of being correct.

8. At what probability should action be taken therefore depends on the cost-loss ratio. This ratio is different for different users, and the probability threshold have to be selected in consideration of other factors appropriate to the individual user.

9. Two examples of such analysis are given here to illustrate.

Case 1

(C) cost of prevention= HK$ -1000
(L) loss without prevention= HK$ -1250

		gain/loss	
		Bad weather	Good weather
forecast probability		40%	60%
Decision	prevention	250 [C-L]	-1000 [C]
	no prevention	-1250 [L]	0

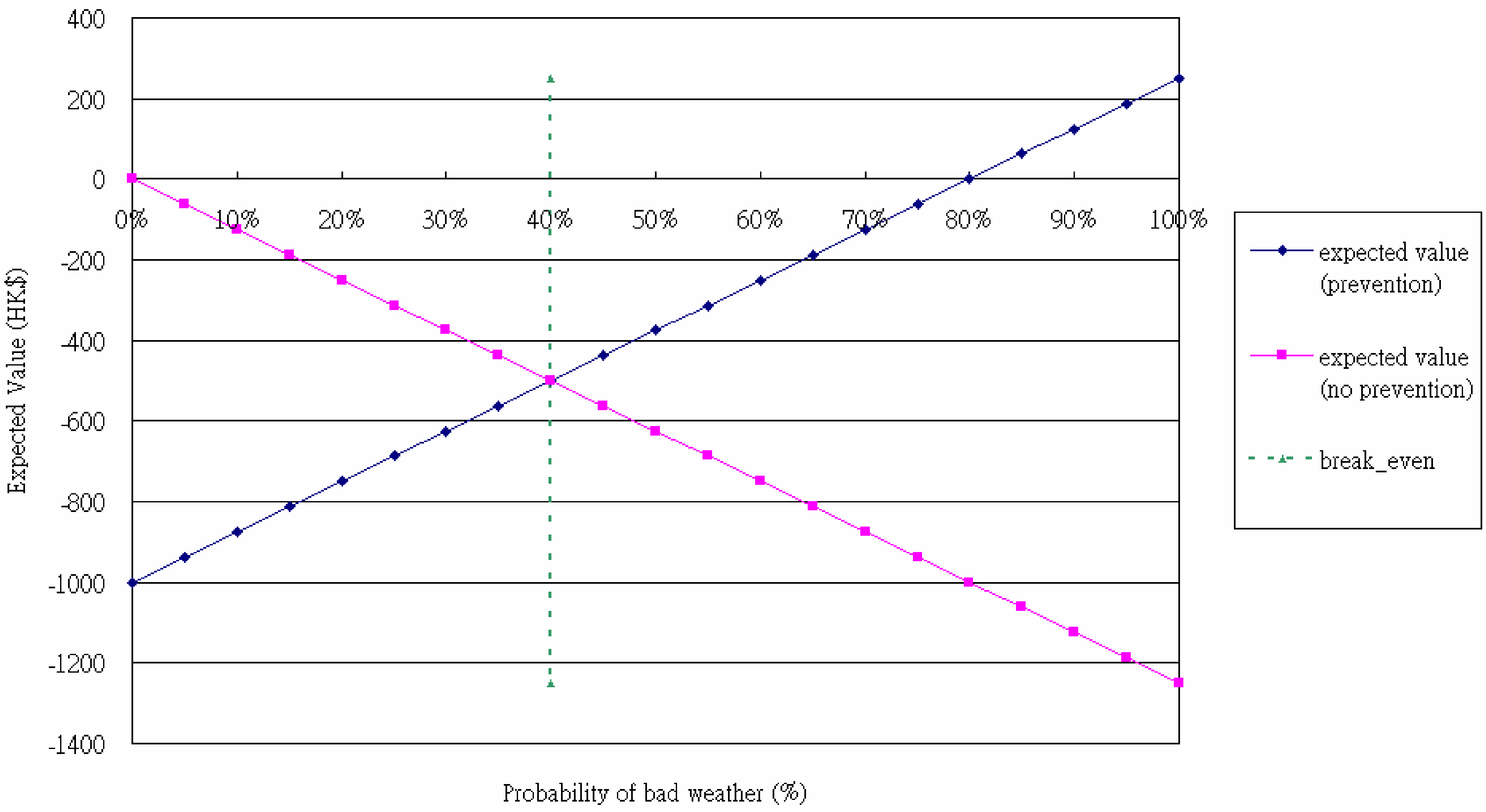
Expected value (prevention) = -500 HK$ =P(bad weather)*(C-L)+P(good weather)*C
Expected value (no prevention) = -500 HK$ =P(bad weather)*L

break-even at 40% 250
40% -1250

Variation of expected values with different forecast probabilities

Probability (bad weather)	expected value (prevention)	expected value (no prevention)
0%	-1000	0
5%	-938	-63
10%	-875	-125
15%	-813	-188
20%	-750	-250
25%	-688	-313
30%	-625	-375
35%	-563	-438
40%	-500	-500
45%	-438	-563
50%	-375	-625
55%	-313	-688
60%	-250	-750
65%	-188	-813
70%	-125	-875
75%	-63	-938
80%	0	-1000
85%	63	-1063
90%	125	-1125
95%	188	-1188
100%	250	-1250

Expected value against probability of bad weather for case 1



Case 2

(C) cost of prevention= HK$ -1000
(L) loss without prevention= HK$ -5000

		gain/loss	
		Bad weather	Good weather
forecast probability		40%	60%
Decision	prevention	4000 [C-L]	-1000 [C]
	no prevention	-5000 [L]	0

Expected value (prevention) = 1000 HK$ =P(bad weather)*(C-L)+P(good weather)*C
Expected value (no prevention) = -2000 HK$ =P(bad weather)*L

break-even at 10% 4000
10% -5000

Variation of expected values with different forecast probabilities

Probability (bad weather)	expected value (prevention)	expected value (no prevention)
0%	-1000	0
5%	-750	-250
10%	-500	-500
15%	-250	-750
20%	0	-1000
25%	250	-1250
30%	500	-1500
35%	750	-1750
40%	1000	-2000
45%	1250	-2250
50%	1500	-2500
55%	1750	-2750
60%	2000	-3000
65%	2250	-3250
70%	2500	-3500
75%	2750	-3750
80%	3000	-4000
85%	3250	-4250
90%	3500	-4500
95%	3750	-4750
100%	4000	-5000

Expected value against probability of bad weather for case 2