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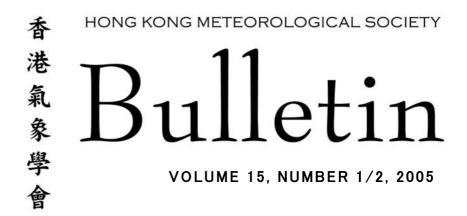
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#### **Editorial**

This issue of the Bulletin combines two issues in one volume and contains four papers and features on society events.

The first paper by Dr. Mickey Man-Kui Wai is a sequel to the paper 'The Early Tropical Cyclone Warning Systems In Hong Kong, 1841-1899' appeared in last volume.

Following Dr. Wai's paper are features on major events hosted by the Society in 2005.

The first feature is an article published in Chinese only which includes all the winning entries of a competition on painting and three-dimensional art for primary and secondary students organized in collaboration with the Hong Kong Society for Education in Art. In this competition, participants were asked to draw a picture or make a model on the topic 'Dancing with Clouds'. The competition attracted participation of over 750 students from more than 30 schools. Winners, teachers and parents shared a happy morning during the prize presentation ceremony on 27 August 2005 and a tour of the Observatory afterwards.

The second feature is on Zhu Kezhen prize awarded in 2005. Two students were awarded the prize – Mr. Wong Tse Man, Ken from University of Hong Kong and Mr. Wu Man Chi from City University of Hong Kong. The Society congratulates the two winners for their achievements. Prizes were presented to them by Society Chairman Mr. Lam Chiu-ying during Annual General Meeting on 23 July 2005.

For readers who enjoyed reading the paper in the last volume on estimated temperature change in Hong Kong in the 21<sup>st</sup> century, they would certainly longed for the second paper in this volume by M.C. Wu, Y.K. Leung and K.H. Yeung of the Hong Kong Observatory which estimates rainfall change in the 21st Century.

The third paper by David Tai-wai Hui, Karen Kit-ying Shum of the Hong Kong Observatory describes convection asymmetries of Tropical Storm Kompasu which landed over Hong Kong on 16 July 2004.

The fourth paper by T.C. Lee and W.M. Leung of the Hong Kong Observatory attempts to identify the seasonal variation of and favorable weather conditions for the occurrence of Japanese Encephalitis cases in Hong Kong.

The Editorial Board would also like to thank Mr. Yu Choi Loi, Weather Observer of the Hong Kong Observatory, for the cover photographs of lenticularis clouds and sunset taken on 27 October 2005 at the Observatory.

# The Tropical Cyclone Warning Systems in the Early Twentieth Century of Hong Kong, 1900-1919

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#### 1. Abstract

The development of tropical cyclone warning systems, according to the local and non local approaches, is traced between 1900-1919.

In order to meet the demand of shipping between 1900-1919, the Observatory introduced two sets of non-local warning code, which did not indicate imminent, bad weather upon the territory. The Observatory used the urgent signal to warn the public when local gales would be expected.

The storm in September 1906 and the subsequent inquiry led to several positive changes. First, it compelled the Observatory to seek new ways to improve the local warning. Subsequently, the Observatory introduced a new local warning system of signals in 1917 to signify directions of gales over the territory. The system of local warning signal in 1917 marked the origin of the current warning system.

To benefit the mariners in the Far East, the Observatory sought a new era of cooperation with other observatories in the Far East, and the cooperation would lead to consider a new uniform system of warning codes for the Chine Seas. To benefit the floating population in the territory, the public and government began to support the construction of typhoon shelters in various locations in the territory in order to deal with however a short notice of the typhoon warning might be so that sufficient time would always be given to boats to proceed safely to a refuge.

The examination of these two approaches has provided some insight not just into the rationale of the warning system but also into the science of the tropical cyclone. It will also clarify if the present warning system is indeed designed for the mariners exclusively. As the study of the tropical cyclone warning system began with the British settlement in Hong Kong, we also learn a brief history of the Hong Kong Observatory. The assessments of the local and non-local warning systems and the public's reaction are also included.

#### 2. Introduction

The use of signals to inform the Hong Kong public about the approach of a typhoon has a long history. Numerous revisions of the warning system and the introduction of new warning system were made. The rationale of these changes that led to the present tropical cyclone warning system, that is evidently unsuitable for the current demographic condition and diverse economic bases and land uses (Wai, 2001), was rarely discussed.

Moreover, as early as in 1877, a black drum was hoisted and a typhoon gun was fired as the means to warn the local residents and mariners about an approaching typhoon. The signals were meant for the probable local bad weather condition. Yet, throughout the early years, the core of the tropical cyclone warning system was meant for non-local purposes. The basis for using the non-local signals was not well documented and understood.

Furthermore, the current condition to display a gale signal has been based on either the observed or expected gales inside the Victoria Harbour since 1973. Therefore, such a condition has led the public to believe that the warning system is aimed to serve the mariners. However, the use of gales inside the harbour, or perhaps the warning system, is meant to serve the mariners exclusively has never been substantiated.

Subsequently, Wai (200x) traced the development of tropical cyclone warning systems according to the local and non-local approaches over four historical periods since the establishment of Hong Kong in 1841. The examination of these two approaches will provide some insight not just into the rationale of the warning system but also into the science of the tropical cyclone. It will also clarify if the present warning system is indeed designed for the mariners exclusively. As the study of the tropical cyclone warning system began with the British settlement in Hong Kong, we also learn a brief history of the Hong Kong Observatory.

Wai (200x) described the tropical cyclone warning systems in the first period (1841-1899). There was no organized typhoon warning during the early years. The warning of a typhoon came only from those mariners who had knowledge of atmospheric signs of an approaching typhoon, or who had experience in working with a barometer on board. It was not until 1870 when Thomsett provided the mariners in port some useful precursory signs of approaching storms in the form of a notice. Starting in 1877, when it was a clear indication that a storm approached Hong Kong, Thomsett hoisted a black drum and firing of a typhoon gun inside the harbour to warn the mariners.

By 1880, Hong Kong, as an entrepot, no longer served primarily as a way station for the triangular trade between Britain, China and India. The trade areas of Hong Kong expanded into Japan, Korea, Southeast Asia, Australia, and United States. The increased shipping led to the establishment of Hong Kong Observatory in 1884. The goal was to instruct the shipmasters on the subject of marine meteorology and terrestrial magnetism necessary for navigating the China Sea and how to avoid the track of approaching typhoons. Therefore, Doberck introduced a non-local tropical cyclone warning system in May 1884. To assist navigation, an outpost lighthouse was built on Gap Rock in 1892. For the local warning, Doberck fired a typhoon gun whenever the local gales would be expected. Between February 1, 1897 and January 28, 1898, Doberck used the modified FitzRoy's system to warn the local residents of local gales. Then the warning system reverted to the system of 1884 at the request of the Hong Kong Chamber of Commerce.

This objective of this article continues to examine the tropical cyclone warning system between 1900-1919, as Hong Kong had become an important port in world trade. Similar to the Wai's study

of the first period (200x), the discussions of the tropical cyclone warning system in Hong Kong are presented according to various eras, during which either a major revision in the tropical cyclone warning system or a new tropical cyclone warning system was introduced. The assessments of the local and non-local warning systems and the public's reaction are also included. Finally, the article will be ended with a discussion.

#### 3. Sources of Documentary Data

Most of the sources used in this article concerning the Hong Kong tropical cyclone warning systems are based on three public records. The first is the Colonial Office Records: Series CO 129, Governor's Dispatches and Replies from the Secretary of State for the Colonies. The second is the Hong Kong Government documents, including Sessional Papers, Administrative Reports, Hong Kong Hansard (reports of Legislature Council Meetings), Hong Kong Government Gazettes, and the Director's Departmental Annual Reports of the Hong Kong Observatory. The third includes several historical newspapers, which are used to provide additional information on the historical typhoons mentioned in the article.

In brevity, the biographical information of the historical and current characters involved in the events will not be given in the article. However, a brief biographical note of each of these historical and current characters is given in Appendix I.

#### 4. Hong Kong Tropical Cyclone Warning Systems

#### a. 1900 - 1916

Around 1902, Froc urged Tyler to adopt the standard time at the Chinese Maritime Custom Service. Without publicity, Tyler sought approval from Hart. Then Tyler quietly persuaded the foreign adviser of the Chinese Telegraph and the manager of the Peking Railway to agree. However, Tyler could not bring Doberck and Rumsey to concur.

Tyler learned that Hewett, the P. & O. agent whom Tyler knew at the detrimental scheme for the conservancy of the Whamgpu River, stationed at Hong Kong. Over a dinner, Tyler explained to Hewett the purpose of adopting standard time. Additionally, Tyler spoke about the relation between time zone and longitude; benefits that resulted to typhoon warnings; what America had done; effect on the regional countries that would follow suits, and the views of Doberck and Rumsey. It was unclear if Tyler also briefed Hewett about the typhoon warning system at Zi Ka Wei Observatory. As the Chairman of Shanghai Municipal Council, Hewett could have known the typhoon warning system at Zi Ka Wei Observatory. Nevertheless, according to Tyler (1930), he did not ask assistance from Hewett or the unofficial members of the Legislative Council; nor mentioned the Hong Kong General Chamber of Commerce.

Surprisingly, Tyler was told that Hewett made a marvelous speech on the standard time and related subjects at the Hong Kong General Chamber of Commerce. In 1904, the standard time was adopted in Hong Kong without fanfare.

At this time, Doberck's warning system provided just a probable location of a typhoon and its distance from the Victoria Harbor. The system did not denote the intensity, and the direction of movement and speed of a typhoon. In term of the information concerning a typhoon, the law of storms, such as those of Redfield, Reid, Piddington and Doberck, readily provided precursory signs of an approaching typhoon, and also principles that would aid the marine captains to avoid a typhoon in the open seas. As shipping had became the cause and reason of existence of Hong Kong, marine captains and shipping companies demanded a more elaborate system that would provide more information of gales in port, and also of a distant typhoon or an approaching typhoon.

In 1903, the Observatory decided to arrange the signals in pair so as to signify the bearing of typhoons from inter-cardinal directions instead of cardinal directions. The use of inter-cardinal points was necessary in order to make the code consistent with the change in the warning system.

At the request of the Hong Kong General Chamber of Commerce, Hong Kong Government adopted the Shanghai Flag system of signaling meteorological information. To hoist these flag signals on January 1, 1904, the government built a mast on Blackhead's Hill (Signal Hill), and Kowloon Point. The reason behind the request was revealed in the exchanges of conversation at a Legislative Council meeting on October 1, 1903:

Blake recommended the Council to approve a sum of \$2,150 for the cost of the mast for the flag signals and for fixing the mast and supplying locker and ball.

Pollock expressed his opinion: The present red drum and cone system worked very badly and was most unsatisfactory. All throughout the previous day and Tuesday there was a red south cone hoisted with the result that most of the junks and native craft went away to the refuge at Causeway Bay. It would be very good thing if the red signal was abolished. It was quite a sufficient warning if the signal was hoisted when a typhoon was within 300 miles of the Colony.

Then the Chairman of the Council stated: The Council was voting this money because the Chamber of Commerce said the signal was not sufficient; they wanted a far more elaborate system. The red signal was not for the information for the harbour boats, but of the masters of vessels about to leave port. In many cases the junk people disregarded the signals altogether. Probably on the day referred to they had thought the weather looked dirty. The red signal did not indicate a typhoon near at hand but more than 300 miles off.

Thomson held that the Government could not be blamed for over-caution on the part of junk-owners.

The Chairman: No; the complaint generally is that the observatory does not give sufficient information.

#### i. Non-local warning system

By 1905, the storm signal system consisted of two sets of codes, which did not mean that bad weather was imminent. The first set of code, primary made up of a cone, a drum, and a ball, was hoisted at a mast beside the time ball at Kowloon Point. For the first time, the Observatory assigned a signal number (1 to 8) to each of the inter-cardinal points for indicating the probable position of the center of a typhoon with respect to Hong Kong (Figure 1a).

Moreover, red signals (indicating that the center of a typhoon believed to be more than 300 miles away from Hong Kong) and black signals (indicating that the center of a typhoon believed to be less than 300 miles away from Hong Kong) remained.

This set of signals was hoisted when typhoons existed in such positions or were moving in such directions that information regarding them be considered to be of importance to the Hong Kong territory or to shipping leaving the harbour. Therefore, similar to the warning system of 1897, the signals served dual purposes: local warning (Hong Kong residents including the boat population) and non-local warning (the visiting mariners who proceeded to leave the harbour).

The second set of code, the Shanghai flag system, consisted of symbols, which represented numerals that would be used to make up of numerical codes for signaling the information of a distant storm. This system became known as the China Coast Code, which appeared to fulfill the original proposal of 1881 so that the ports along the China coasts would use one uniform set of warning codes. In 1906, rattan shapes replaced the flags.

The China Coast Code, hoisted at the Blackhead's Hill, consisted of six symbols corresponding to the numerals 1 to 6 (Fig 2). The symbols were arranged to three groups signaling the information of a typhoon. The first two groups were the typhoon or continental depression signals while the third was the gale signals.

#### Figure 1a. Hong Kong Meteorological Signals 1905.

Meteorological Signals are hoisted on the Mast beside the Time-Ball at Kowloon Point for the information of Masters of Vessels leaving the Port. They do not imply that bad weather is expected here.

Signal No. 1	3 a cone point upwards indicates a typhoon to the north of Hong Kong.
Signal No. 2	∃ a cone point upwards and drum below indicates a typhoon to the north-east of Hong Kong.
Signal No. 3	a drum indicates a typhoon to the east of Hong Kong.
Signal No. 4	% a cone point downwards and drum below indicates a typhoon to the south-east of Hong Kong.
Signal No. 5	% a cone point downwards indicates a typhoon to the south of Hong Kong.
Signal No. 6	$\%$ a cone point downwards and ball below indicates a typhoon to the $\forall$ south-west of Hong Kong.
Signal No. 7	$\forall$ a ball indicates a typhoon to the west of Hong Kong.
Signal No. 8	∃ a cone point upwards and ball below indicates a typhoon to the north- ∀ west of Hong Kong.

Red signals indicate that the center is believed to be more than 300 miles away from Hong Kong.

Black signals indicate that the center is believed to be less than 300 miles away from Hong Kong.

#### Night Signals

Two lanterns hoisted vertically indicate bad weather in Hong Kong and the wind is expected to veer.

Two lanterns hoisted horizontally indicate bad weather in Hong Kong and that the wind is expected to back.

The signals are repeated on the Flagstaff of the Godown Company at Kowloon, and also, by day only, at the Harbour office and on H. M.'s Receiving Ship.

#### Local Storm Warnings

The Colony itself is warned of approaching typhoons by means of the Typhoon-Gun placed at the foot the mast, which is fired whenever a strong gale of wind is expected to blow here.

#### Figure 1b. Hong Kong Meteorological Signals 1907.

#### Urgent Signals

In addition to the above, which it is expected that the wind may increase to full typhoon force at any moment, the following Urgent Signal will be made at the Water Police Station, and repeated at the Harbour Office.

Three explosive bombs, at intervals of ten seconds.

A black cross will be hoisted at the same time, superior to the other shape.

#### Night Signals'

The following Night Signals will be exhibited from the Flagstaff on the roof of Water Police Station at Kowloon, the Harbour Office Flagstaff, and H.M. S. Tamar.

- I. Three lights in vertical, Green Green, indicate that a typhoon is believed to be situated more than 300 miles from the Colony.
- II. Three lights in vertical, Green Red Green, indicate that a typhoon is believed to be situated less than 300 miles from the Colony.
- III. Three lights in vertical, Red Green Red, indicate that the wind may be expected to increase to full typhoon force at any moment.
- No. III Signal will be accompanied by the explosive bombs, as above, in the event of the information conveyed by this signal being first published by night.

These night signals will be substituted for the day signals at sunset, and will, when necessary, be altered during the night.

#### Supplementary Warnings

For the benefits of native craft and passing ocean vessels, a cone will be exhibited at each of the following stations during the time any of the above day signals are hoisted in the Harbour.

Gap Rock, Waglan, Stanley, Cape Collinson, Aberdeen, Sai Kung, Tai Po.

This will indicate that there is a depression somewhere in the China Sea, and that a storm warning is hoisted in the Harbour.

Figure 2. The China Coast Code, 1905.

Symbol	<b>‡</b>	<b>†</b>	Υ	Φ	4	₾
Corresponding number	1	2	3	4	5	б
F	ositio:	n of the	e Center	(3 symb	ols)	
Series 1 = ♥	Series	; 2 = <b>†</b>			Series	3 = <b>Υ</b>
SE District	SWI	)istrict			S Cen	tral District
No. Meaning 111 Caroline Is Pelew (Yap) 112 Mariana Is (Guam) 113 Between Mariana & Bonin Is 114 Far to the E of Philippine Is 115 SE of Luzon 125 Sulu Sea 123 SW of Luzon 124 E of Luzon 125 Central Luzon 126 W of Luzon 131 NE of Luzon 133 NE of Luzon 134 NW of Luzon 135 W of Palawan Is 136 SE of Macclesfield Bk 144 S of Macclesfield Bk 145 S of Paracels 156 NE of Paracels	212 S 213 C 214 E 215 E 216 E 222 T 223 C 224 E 225 S 236 S 237 S 238 S	W of Pan Off Tours Setween I Setween I Sof Hain Ongking Off the Do Iainan St E of Hong W of Hong W of Ho Coast near Coast of F IW of Ho Off Swato Off Swato Off Amoy	ast of Co- racels on (Anna- Paracels of Hainan &  an Is  Gulf  elta of the  rait  ng Kong v  g Kong v  Kong Kong  ng Kong  oosa Chan  oog Kong  oosa  oosa	& Hainan Annam Sungka seyond 200 vithin 200	312 C 313 S 314 S 315 S 316 S 322 N 323 V 324 S 0 325 E 333 S 334 S 335 C 336 N 344 N 345 C	Meaning Cof Loochoo Is (Luchu) Central Loochoo Is (Luchu) E of Loochoo Is (Luchu) of Loochoo Is (Luchu) E of Meiaco Sima group of Formosa Callintang Channel Casbee Channel W of Formosa Central Formosa Central Formosa Centra of F
Series 4 = ∰	Serie	s 5 = 4			Series	6 = ↔
N Central District	N	l District			Conti	nental Depression
No Meaning	No	Mear	uing		No	Meaning
411 NE of Loochoo Is (Luchu) 412 NW of Loochoo Is (Luchu) 413 NW of Loochoo Is (Luchu) 414 Off Tung-Yung Lt 415 SE of Wenchow 416 SE of Hie-shan Lt 422 Coast of Chi-kiang 423 SE of Chusan Is 424 SE of Gutzlaff Lt 425 Off the Saddle Is 426 S of Shanghai 433 SW of Shanghai 434 E of Shanghai 435 W of Shanghai 436 NE of Shanghai 436 NE of Shanghai 444 NW of Shanghai 445 N of Shanghai	512 513 514 515 516 522 523 524 525 526 533 534 535 536 544 545	N part of E of Nip Centrall Wof Nip SE of Ni Approac Approac SW of K Worea St E of Korea SE of Sh SE of Tsi E of Sha NE of Sha	Tippon upon ppon hes to Ki hes to Bu insiu usiu ea antung intau dau ntung nantung	of Japan Chammel	612 U 613 N 614 L 615 U 616 L 622 N 624 S 625 E 626 E 633 S 634 K 635 E 644 S 645 E	astern Manchuria Yellow Sea ea of Japan astern Sea
446 Between the Saddles & Quelp 455 Central Yellow Sea 456 Coort of Viewery	555	GulfofF	echili			ezo Is (Hokkaido)
456 Coast of Kiangsu	טככ	Liaotung	СШ		000 E	of Nippon

		S	Signals	of Dire	ection (2	Syml	ools)	
Symbols	Ð	₩	Ф	*	*	*		
	Ŧ	Ф	<b>\$</b>	<b>\$</b>	*	<del>†</del>		
Meaning	N	NE	E	SE	s	sw	·	
Symbols	<del>+</del>	Ð	Υ	า	Ω		Υ	<u> </u>
	<del>+</del>	<del>+</del>	Υ	2	<u>ਨ</u>		<u> </u>	<u>≏</u> Υ
Meaning	W	NW	Recu	rring	Steady Very sl		Filling up	Unknown
φ Coa γ For	st of Indo mosa Is an	Des Philippine I -China, G	scriptio I, China ulf of To I, Coast	n of the Sea, So ongking of Chir	e Section outh of Pr , China S na, betwee	ratas I Sea, W en Sw	Reefs and E of the Para atow and W	
<u>Ω</u> Sea	and Coast	s of Japan	, E and	5 of K	orea, (Loc	ochoo,	) Luchu Isla:	nas

The first group indicated the position of the center of a typhoon. Each of the six symbols represented a district where a typhoon could be found. For instance, the numeral 2 referred to the south district. Then the location of a typhoon with respect to a landmark within a district was given by three symbols; the first of the three symbols was the symbol of the district. For instance, code 233 meant that the center of a typhoon was located south of Hong Kong. There were 120 possible codes in this group.

The second group was the signals of direction, which were made up of two symbols. There were 12 signals. Eight of them corresponded to 8 inter-cardinal points toward which the center of a typhoon was traveling. The rest indicated recurring, steady or very slow, filling up and unknown.

The third group, made up of one symbol, represented the regions threatened by gale.

To convey the position of the center of a typhoon, three symbols were hoisted at the one-yard arm, and two symbols at the other yard-arm would show the direction of motion of the typhoon. For the gale signals, two symbols at the one-yard arm would show the general direction of the wind, and one

symbol at the other yard-arm would show the region threatened.

The purpose to adopt the China Coast Code is to provide the captains and shipmasters the movement and wind speed about a distant typhoon. However, the vague location of a typhoon position, such as South of Hong Kong, or southwest of Luzon, was a major reason that the code was not well received, in particular among the local residents.

In 1908, mariners began to use wireless telegraphy to send weather reports. Because of the advance in communication, the interest in the construction of new remote weather stations grew. For instance, on at least two different occasions in 1909 and in later years, Pollock (on March 11<sup>th</sup>) and Hewett (on October 21<sup>st</sup>) questioned the Hong Kong Government if arrangement would be made for signaling of typhoons by wireless telegraphy from the Pratas Island (Tungsah Dao), about 170 miles southeast of Hong Kong. Then in 1910, the Imperial Chinese Telegraph Administration agreed to erect a wireless telegraph station on Pratas Island. In return, five of their operators would receive training in meteorological observations at the Observatory.

In May 1912, the inter-cardinal points in the signals of direction in the China Coast Code were increased to 16 compass points when signaling the track of typhoons.

On August 27, 1915, the Hong Kong Government requested the masters of vessels, who possessed wireless telegraphy installation, to exchange meteorological observations with the Observatory in the work of forecasting and storm warning. The wireless weather telegrams began to come in from Japanese and Dutch ships in 1916.

#### ii. Local warning system

The local storm warning system was still given by the firing of a typhoon gun whenever a strong gale of wind was expected to occur in Hong Kong. The practice of one to three rounds of firing typhoon gun was eliminated.

The night signals included two sets of lanterns. The first set of two lanterns, hoisted vertically, indicated that bad weather in Hong Kong and that the wind was expected to veer. The second set of two lanterns, hoisted horizontally, indicated bad weather in Hong Kong and that the wind was expected to back.

In 1907, the Observatory replaced the firing of a typhoon gun in the local warning system with an urgent signal (Fig. 1b). Whenever the wind might increase to full typhoon force at any moment, three explosive bombs were detonated at an interval of ten seconds at the Water Police Station and the Harbour Office. Simultaneously, a black cross was hoisted.

At night, the night signals of the vertical and horizontal lights were replaced by three sets of vertical lights, each of which consisted of three colors of light. The first set was Green Green Green, indicating that a typhoon was believed to be situated more than 300 miles from Hong Kong. The second set was Green Red Green, indicating that a typhoon was believed to be situated less than 300 miles from Hong Kong. The third set was Red Green Red, indicating that the wind might be expected to increase to full typhoon force any moment. The night signals were displayed at flagstaff on the roof of the Water Police Station at Kowloon, the Harbor Office, and H. M. S. Tamar.

For the benefit of the native vessels and passing ocean vessels, a cone was displayed at Aberdeen, Cape Collinson, Gap Rock, Sai Kung, Stanley, Tai Po, and Waglan Island whenever the day signals were hoisted in the harbour.

#### iii. Typhoons in the South China Sea

As early as 1886, Doberck knew that the typhoons came out over the Philippine Sea. Most of these typhoons followed a similar track along the SE-NW direction. After these typhoons crossed over Philippine Islands into the South China Sea, most of these typhoons would make landfall somewhere along the China coast. Therefore, when a typhoon moved across Philippine Islands, the observatories along the China coast would find a telegraphic report containing the direction of movement, intensity, and the speed of a typhoon from Manila Observatory extremely valuable. Similarly, the staff at the Manila Observatory recognized that Philippine Islands were located in the entrance of a typhoon alley; the staff began to document the passages of typhoon and analyze the surface pressure field of a typhoon, especially the nature of the eye of the typhoon, for the benefits of the typhoon forecasting in the South China Sea basin.

Several documents, available in English language, described the progression of typhoons over Luzon, the northern Philippine Island (Coronas, 1908), central Philippine Islands (Coronas, 1909), and Batanes Islands and southern Formosa (Coronas, 1911), from the Pacific Ocean into the South China Sea. Using the surface stations over Philippine Islands, China coast, Formosa, Guam, and Yap in the surface analysis, Coronas noted that the vortex was modified as it moved across the Philippine Islands. In one case, a typhoon re-intensified after entering the South China Sea. These studies traced the origin of the typhoon to 140  $^{0}$ E, further than what Doberck suggested.

Several years earlier, motivated by the work of Chevailer (Zi Ka Wei Observatory), Algue (Manila Observatory) and Doberck, Bergholz published *The Hurricanes of the Far East* in 1899. In writing *The Hurricanes of the Far East*, Bergholz drew the materials heavily from the observational records made at the Manila Observatory. The book consisted of general remarks of the tropical cyclone, characteristic cyclones, and winter storms and land storms.

One important aspect of the book was the discussion of the eye of the typhoon. The surface pressure reaches the minimum from two minutes to at the beginning of the clam. The rise of the surface pressure occurs from several minutes to at the end of the clam. The changes of surface wind were more variable as when the surface wind was stronger before and after the calm. Inside the eye, the air temperature is relative higher and the relative humidity is lower than those outside the eye. However, different views were on the questions if air is ascending or descending inside the eye.

Another important aspect of the book was the discussion of two different views on the formation of a tropical cyclone. The first was attributed to the mechanical process of interference of two air currents that met at an angle (mechanical theory). The cause of the low surface pressure in the center of the cyclone was due to centrifugal force, which was a result of rotational air. This view may explain the origin of a cyclone in an isolated situation, but it cannot explain its origin, development, duration, and progression of a cyclone.

The second view was attributed to the physical process of diverting influence of earth rotation upon the mass of air moving towards a low surface pressure center. Accompanied with the rotational

flow was a copious condensation of water vapor as a result of convection (thermal theory). The latent heat produced an accelerated ascent of air above the cyclone and reinforced the inward flow of air at the surface. The maintenance of the energy of a cyclone lied in the condensation of water vapor embedded within the circulation of a cyclone. This view can explain the origin, development, duration, and progression of a cyclone without taking sufficiently into consideration the first cause of the low surface pressure center. It is because a tropical cyclone occurs in some preferable regions within the tropics.

#### iv. Dealing with a short notice of the typhoon warning: construction of typhoon shelters

Following the typhoon in 1874, the public opinion demanded that the Government took action to safeguard the floating population. According to Cameron (1991), Hennessy proposed to build a breakwater in Causeway Bay by converting part of Causeway Bay into a harbour of refuge (typhoon shelter) for the native vessels (sampans, launches, junks) and the boat population. The construction started early in 1880 and completed by the time the Observatory was officially opened in 1884 (see Bowen's opening speech of the session of 1884 of the legislative Council of Hong Kong).

It was not until 1898 when Leigh wrote about the need of a breakwater in Belchers Bay (off Kennedy Town) in the west end of the harbour in the newspapers. Having read the article, Stewart initiated correspondences among Leigh, the Chamber of Commerce, and the Government. Moreover, Stewart consulted Denison, who knew the harbour well, the feasibility of a typhoon shelter in the west end of the harbour. Denison drew a plan of a breakwater, which would create 80 acres of harbour of refuge by connecting from the north of Green Island and a smaller island to the east. Since the water there was shallow, the proposed refuge could be built at very little expense.

In the same year, the Chamber of Commerce favoured the construction of a new typhoon shelter near the Slaughter House in Kennedy Town at an estimated cost of \$100,000. The Government was unable to undertake the construction due to lack of funding.

Following the storms in 1901 and 1902, the public demanded that the government should do something to provide greater protection to the boat population during the typhoon season (Lack, 1973). So it was at a Legislative Council Meeting on December 14, 1903, Stewart rose to move a resolution:

That, in the opinion of the Council, it is advisable to increase, if possible, the means of shelter for cargo boats and sampans during the typhoon season.

We might bear in mind that the harbour is after all the reason of our existence here, from the harbour we directly and indirectly, all of us, depend on our subsistence. We are now in the position of having abundant revenue. .... I now put a plea for a humble and hard-working section of seafaring population who have no means of advocating their own causes.

In closing his speech, Stewart recommended the resolution to the Council on two grounds:

1) The first being that of self-interest, for we indirectly will get some benefit because of we are doing something to assist trade.

2) On the higher ground of our common humanity, for I think it is right and proper that we should afford all the protection and help we can to an industrious and hard-working section of the community, who during a certain part of the year may claim to be following a dangerous avocation, because we must remember that these people in numbers, men, women and children, have nothing between them and the next world but perhaps a half inch plank when it may be blowing a hurricane in the harbour.

Dickson seconded the resolution. However, representing the Government, Thomson explained that:

I am authorized to say on behalf of the Government that we are fully aware of the need of new accommodation such as is indicated in the resolution. Only lack of funds has been the difficulty hitherto in connection with this increase. Steps have been taken just now to obtain definite plans for the construction of the harbour refuge at the west end of the Harbour. Meantime the Government has no objection to pass the resolution.

To lower the expectation, May added,

I hope honorary members will understand that the difficulty hitherto had been want of funds, and the remark put forward by Thomson is not intended to indicate that the difficulty has been got over-I am not in a position to state that-, but the matter is regarded as urgent.

Nonetheless, the resolution was agreed to.

On June 15 1904, the Government notified the Chamber of Commerce of a proposed construction of a new typhoon shelter at Mong Kok Tsui, which had a breakwater of 4000 feet long and a shelter area of 166 acres, with an estimated cost of \$600,000. In the notification, the government just sought the Chamber for any comments; how to finance this typhoon shelter was not even mentioned.

In the reply to the proposed construction a month later, a Committee of the Chamber of Commerce (here refer to The Committee) did exactly what the Government requested, by commenting the construction of a new typhoon shelter. Among many other things in the reply, four areas stood out. First, the committee welcomed the construction of a new typhoon shelter since those who needed shelter in the west end of the harbour frequently sailed against the head wind or required to employ steam launches to tow them to the shelter at Causeway Bay when typhoons approached.

Second, Mong Kok Tsui was not a good site; instead Cheung Sha Wan was a better site because of its easy access by those from the west end of the harbour and better protection from the local terrain.

Third, the usefulness of red storm signals in the warning system was once again under scrutinized. It had became a common practice that the owners of native vessels and their crews terminated the work unnecessarily early and ran for the shelter as soon as the Observatory hoisted a red storm signal even though the red storm signals did not refer to imminent bad weather upon the harbour. Consequently, the practice caused a serious inconvenience to shipping in the harbour because the shipping companies relied on native vessels to move cargos between vessels and warehouses along the shore.

Since a red storm signal signified that a typhoon was over 300 miles away, the native vessels were unnecessarily required to seek a typhoon shelter immediately. A second shelter would allow the

owners of native vessels to reduce the length of time needed to reach a typhoon shelter nearby. Therefore, the Committee went on to say:

My committee therefore trusts that on completion of the larger harbour the Government will abolish the red symbols and regard the hoisting of the black symbols only as a sufficient warning to small craft of the proximity of a typhoon.

Fourth, the Committee neither offered any monetary aid nor mentioned any schemes on financing the construction of a second typhoon shelter.

The years 1904 and 1905 went by without action on the proposed shelter. Then in front of the Legislative Council on December 31, 1905, Nathan gave a budget of the coming year in which had a list of large number of projects. The new typhoon shelter remained among the projects to be begun only when the financial situation would allow it.

On September 13, 1906, Nathan spoke the estimate of revenue and expenditure for 1907. Concerning the new proposed typhoon shelter, Nathan stated that

One of the items which I wished to appear on the Estimates for the year but which does not appear is the typhoon shelter. So long as we have those waterworks on hand to which I have referred there is very little chance of doing anything in connection with the shelter; unless the Chamber of Commerce would suggest raising the light dues to provide funds for its construction, in which case such a reasonable suggestion might be adopted.

Coincidentally, a violent storm hit Hong Kong on September 18, 1906. The loss of human lives and properties were devastating. The deaths ranged from 4000 to 10,000 (the majority of the deaths was boat people). Two days later at a Legislative Council meeting, Nathan gave a preliminary report to the legislative members about the disaster. To assist the victims, Nathan appointed a Typhoon Relief Fund Committee, headed by Hunter, to collect funds for the victims.

At a legislative Council meeting on September 27, 1906, Hewett argued from the historical funding records that light and tonnage dues were not to be raised for the purpose of general revenue. Based on who would be the beneficiaries, Hewett insisted that the shipping community alone should not shoulder the cost of the shelter. Furthermore, Hewett suggested that the new shelter could be financed by a loan.

Representing the native population, Ho was disappointed by the fact that the Chamber of Commerce should not be expected to come forward to aid the Government on the construction of a new typhoon shelter. He went on to deliver a vivid speech, which established a principle for the construction of future typhoon shelters:

It seems to me, taking all the facts of the recent calamity into account, that although warning might have been given earlier by the Observatory, it would not under the present circumstances, have saved many of the boating people from disaster; because considering the long stages of water many of them had to cover, the chances are that few would have reached the refuge. It would be much better in future to have a number of typhoon shelters so that however short of the warning might be, sufficient time would always be given to boats to proceed safely to a refuge.

Ho argued passionately that the necessity of the construction of a new shelter was not only on the ground of expediency, but also on the ground of humanity. Ho even supported the idea that the Government would undertake the construction immediately either by means of a loan or otherwise. Another representative of the native population, Wei urged the Government to seriously consider the question of speedily construction of a new typhoon shelter. Wei believed that Chung Sha Wen or Mong Kok Tsui was the only site for the construction of the new typhoon shelter.

Having listened to the legislators, Nathan pleaded to start the typhoon shelter in the coming year. Nathan declared against taking out a loan to finance the construction of a typhoon shelter. He believed that

We should pay for what will benefit the next generation in the same way as the past generation paid for the benefits, which the present generation enjoy.

#### Nathan went on:

If the cost of the typhoon shelter is not to be met by a loan, and I think I have the majority of the Council with me that it should not be met, the question whether additional taxation should be imposed by higher assessed taxes or light dues will have to be considered. I hardly think the honourable member who represents the Chamber of Commerce can be allowed to have the last word on the subject. He stated that Hong Kong depended entirely on its shipping. I know that is the usual way of putting the case, but is it really the correct way? Does not Hong Kong depend as much on its trade as its shipping? Would the shipping exist without its trade? I think not. The shipping makes its profits – and I imagine they are large ones-from Hong Kong, and it is not clear why those profits not be taxed? At any rate, that is not a matter I need settle at the present moment.

In the end, Nathan would decide how the necessary expenditure could best be met in financing the construction of a new shelter.

In a later meeting held by the Financial Committee on November 1, 1906, Chatham presented reports that described several sites for the new typhoon shelter and their estimated cost for review.

Mong Kok Tsui	166 acres	\$600,000
Cheung Sha Wen	166 acres	\$600,000
Stonecutters	107 acres	\$765,000
Kellett's Bank	136 acres	\$1,170,000
Kennedy Town	32 acres	\$360,000
-	75 aces	\$600,000

Hewett was in favor of the typhoon shelter either at Mong Kok Tsui or Cheung Sha Wan. Another committee member, Gresson, stated that the boat population was in favor of another site in the Western District in Kennedy Town. The committee considered that, unless the government could undertake construction at both sites, precedence should be given to the one at Mong Kok Tsui.

After full discussion, it was unanimously agreed to recommend the construction of a typhoon shelter

at Mong Kok Tsui.

At the Legislative Council meeting on the same date, Pollock asked when would the Government intend to commence work on the construction of a new typhoon shelter. Chatham replied that as soon as the necessary plans and estimates could be prepared.

The Government forwarded a report on the subject of a new shelter and several proposals to the Chamber of Commerce on December 18, 1906. In a reply to the Government on March 25 1907, the Chamber of Commerce stated that the Committee was unanimously of opinion that the best proposal put forward was that providing a shelter at Mong Kok Tsui.

Just before Nathan finished his term as the Governor on April 16, 1907, Nathan reconfirmed his pledge that a new typhoon shelter would be built at Mong Kok Tsui in his letter acknowledging the laborious efforts of the Typhoon Relief Fund Committee in collecting funds for the typhoon victims. Two days later, Nathan informed his Superior in London office that a new typhoon Shelter would be built at Mong Kok Tsui with the estimated cost of \$600,000. The site was selected based on the recommendation of Public Works Committee and the Legislative Council.

In the Legislative Council meeting on October 3, 1907, the Council members learned that the estimate of the new typhoon shelter was escalated to \$1,400,000. Besides complaining that the Legislature was entirely in the dark as to how the new estimate had been arrived at, Hewett was disappointed that the Government would appropriate \$25,000 for construction in the following 18 months. Hewett stressed that the public did not want a grand shelter but an efficient breakwater sufficiently high to give protection to all the boats in the harbour. Therefore, the work of new typhoon shelter is urgently required. Moreover, Hewett indicated that the harbour at Causeway Bay was allowed to silt up and a large number of boats were compelled to lie outside the shelter. Therefore, the dredging of Causeway Bay was a matter of urgency.

Osborne, another Council member present at the meeting, was not so polite in response to the Government's plan,

The history of Hong Kong, Sir, is burdened with records of these dangerous storms, meaning so much to those whose lives are passed upon the frail craft that ply the waters of our harbour; so much to shipping, the life blood, as we are apt to put it, of Hong Kong boasting the largest tonnage in the world. And what have we, with the lessons of 1874 and subsequent typhoons before us, what have we done to nourish this life blood, to protect the craft so essential to its being; to preserve the port against the evil reputation of being a dangerous anchorage? From the records of the Observatory, now 25 years old, it would be interesting to learn how many times during that period we have suffered actual contact with typhoons and how many times they have, so to speak, grazed our door, and Hong Kong escaped by a hair's breath. And what have we done during those 25 years? Absolutely nothing; indeed, worse than nothing, because we have permitted the Causeway Bay shelter, built in 1882 by men who were in this respect better men than we, we have permitted the shelter to silt up to such an extent, that at low water a large proportion of it is dry land.

A year ago, public and official opinion were agreed that a new shelter was a work of urgent necessity and a new shelter was accordingly decreed, but a year has gone, Sir, and this work of urgent necessity has apparently not passed the initial stage of plans and discussions. From your

Excellency's remarks when introducing the estimates I gather that the breakwater is to cost \$1,400,000 of which \$25,000 are provided for next year. The figures, Sir, are ominous, fourteen hundred thousand dollars, at \$25,000 a year means 56 years to complete, and were it not for your Excellency's promise that more than \$25,000 will be spent if needed, I should be inclined to judge from its beginning, that the end of the scheme was very long way off.

During a rather long residence in Hong Kong I have had exceptional opportunities of coming into contact with the boat population. Though like most humanity their character is a blend of the good and the bad, there is one quality they possess in marked degree which has always commanded my deep admiration and that is their patience and philosophic nearing under circumstances of trial and suffering. In their name, Sir, and apart from the commercial aspect to which I have alluded, in the name of thousands who have already suffered in silence the misery wrought by these destructive storms, I appeal to your Excellency that there shall be no further delay in giving them the shelter which it is our clear bounden duty to provide.

On December 19 1907, Chatham informed Lugard that the committee examined the final plan and the cost on the proposed typhoon shelter at Monk Kok Tsui. In addition, the committee discussed Taylor's recommendation that a typhoon shelter should be built at West Point instead of at Mong Kok Tsui. It was decided that the final proposal on the Mong Kok Tsui and other documents be circulated among the legislators for studying the matter.

Then on March 11, 1908, the Government informed the Chamber of Commerce that a new typhoon would be built at Mong Kok Tsui.

Because of the typhoon on September 18, 1906, the estimate for the new typhoon shelter would be \$1,540,000. To dredge the shallow areas in the shelter at Causeway Bay, an estimated cost of \$70,000 would be needed.

To finance the construction of the new shelter, the Government proposed a scheme: half of the cost would be paid by the government's reserves, and the other half would by paid for by the temporary increase in fees on shipping:

His Excellency proposes to temporarily increase Light Dues on ocean going vessels to 2.5 cents per ton and on river steamers to 5/6 ths of a cent per ton for each entry by day or by night as from the 1<sup>st</sup> of June next, such increased rates to be maintained until the receipts from addition of 1.5 cents imposed in the one case and of 0.5 cent per ton for each entry by day or by night in the other, aggregated the sum of half the cost of the improvements detailed above.

In response to the Government's new proposed taxation, the Committee stated that the amount of increased fees was too great on shipping. Other private sectors ought to contribute a portion. Also the Committee urged that the sum to be raised should be spread over a longer term of years. However, the Government remained firm on the scheme how to finance the construction of a new typhoon shelter.

Realizing that the Committee's view on how to finance the new typhoon shelter was not well received, the Committee forwarded the Government's plan and estimates to the general body of British shipping companies or their agents for their consideration and response to the proposal. On

June 23, 1908, this body of British shipping companies protested to the Chamber:

Memorandum From the British Shipping Lines to the Chamber of Commerce re Light Dues

Typhoon Shelter- if the Government has not definitely decided to build the new Harbour of Refuge at Mon Kok Tsui there are various reasons against the site:

Too big-contemplated size not required at present-unwise to build as intended when necessity is not apparent.

Cost- prohibitive in Colony's present financial condition.

Accessibility- it is no more accessible than the present refuge.

These reasons are all in favor of first improving the present site at Causeway Bay (which is in a disgraceful state), and watching the results. In favour of this it is contended that:-

Cost of dredging is not excessive.

Accessibility is equal to new site proposed.

Area is large enough for all practical purposes. Lighters and large junks can ride at anchor as they have always done, and small craft can be well accommodated at Causeway Bay in ordinary typhoons.

Safety of craft- for a typhoon unsignalled, as in 1906, no refuge of any size or description or situation would be of any avail.

Mong Kok Tsui Shelter- Suggested method of meeting cost-If the Government is definitely committed to the Mong Kok Tsui scheme there is nothing further to be said except for the shipping to present their views as to financing the work. They would repeat that this should be arranged to extend over a longer period than the proposed by the Government and that the extra tax on shipping should not exceed 0.5 cent per ton net register. The financial arrangements should be separate and distinct from the General Finances of Hong Kong. This can be done if necessary without the Government contracting a special loan. Any of the local banks will be glad to lend the money as an ordinary overdraft at 6 percent if guaranteed by the Government, the shipping Companies guaranteeing to pay extra payment monthly into the Bank providing the money, of the total realized by the extra 0.5 cent, together with an equal amount representing the Government's half share of the cost. By this means the urgency of the work suffers no delay.

The general body of British shipping Companies included P. & O. Steam Navigation Co., Butterfield & Swire, Jardine Matheson & Co. Ltd., Dodwell & Co. Ltd., Canadian Pacific Railway Co., Douglas Lapraik & Co., Gibb Livingston & Co., Shewan Tomes & Co., McGregor Bros. & Gow., Hong Kong, Canton & Macao Steamboat Co. Ltd., and David Sassoon & Co. Ltd.

Meanwhile at a council meeting on July 24, 1908, the Governor recommended the Council to vote a

sum of \$186,500 in aid for constructing the new typhoon shelter at Mong Kok Tsui. The government already purchased a dredger for the work at Mong Kok Tsui and planned to put the dredger for sale after the completion of the new shelter. When Pollock pointed out that the work could have been done at a lower cost, the Chairman stated:

I am prepared to say that His Excellency has intimated that he is not prepared to re-open the question of a site for a breakwater. The site of this breakwater has been practically fixed, but the question of finance it, is, of course another mater. But in view of the widely expressed public opinion that there should be an additional shelter, and in view of the references to every conceivable body that could be considered to give a good opinion on it, the scheme had been adopted by the majority. I think you may take it, gentlemen, that in voting this money you are assisting the Government to carry out what is regarded as fixed policy-that is, to build the breakwater at Monk Kok Tsui, come what may be the results of the consideration of the Public Works Committee and other bodies, and the Government's own review of all possible schemes.

The Committee's new position on the new typhoon shelter surprised the Government. On July 25, 1908, the Government explained to the Committee that the construction of a new typhoon shelter was to fulfill Nathan's pledge. The project also won the support of un-official members of Legislative Council, Typhoon Relief Committee, Public Works Committee, and the community. For the loan, the Government would not consider taking a loan as an option. To win the Committee's support, the government proposed to limit the temporary increase to 2 cents instead of 2.5 cents per ton, and to exclude the cost of deepening Causeway Bay from the special funds towards which the additional dues were to be devoted. Moreover, the Government informed the Committee that a tender was already accepted for deepening the southern portion of the Causeway Bay shelter to a depth of 1 foot below low water of ordinary Spring tides. Work would commence on this immediately.

The experience of another typhoon of July 27-28 1908 hardened the Chamber's view that the shelter at Mong Kok Tsui was unnecessary. According to the Chamber,

With only 5 hours' notice from the Observatory of the approach of the typhoon within the 800 miles radius, comparatively little damage was done to small craft, and the loss that did occur might have been greatly reduced had the Observatory been able to ascertain the near proximity of the storm, which they were apparently unable to do, judging from the fact the black signals were not hoisted until 6 p. m. and that the gun was fired about 11 p. m. when the typhoon actually upon the port.

The Government's ambiguous message on the site of the Causeway Bay did not make the negotiation any better. It was hinted that the Government tended to fill the Causeway Bay by reclamation when the proposed shelter at Mong Kok Tsui was completed. If this was the Government's intention, the Committee suggested that the money eventually obtained by the sale of the new land should be earmarked to reimburse the cost of the Mong Kok Tsui scheme if the Government were determined to proceed with the work.

Then on August 6, 1908, Lugard asked the Council members to accept the resolution concerning the financial scheme for the new typhoon shelter.

Be it resolved on and from the 1<sup>st</sup> January 1909, the owner, agent or master of every ship which enters the waters of Hong Kong shall pay the following dues to such officer as the Governor may

from time to time appoint:-

- (1) For all river steamers which enter the waters of Hong Kong by day or by night: five-sixths of a cent per ton register
- (2) All other ships which enter the waters of Hong Kong: two cents per ton register
- (3) Exemption: British and foreign ships of war.

Before asking for the votes, Lugard gave a lengthy rebuttal to the shipping community's main arguments to the opposition of construction of a new typhoon shelter. Mainly, the government took concession by reducing the proposed tax from 2.5 cents to two cents, and spreading a period over eleven years instead of five years. On a question about the future proceeds incurred from reclamation in Causeway Bay, Lugard could not gave any firm answer to the question as he had no authority to impose the future governor what to do. Finally Lugard said,

The Government is unable to recede from its position that the refuge is absolutely necessary, and that the minimum which we can ask from the shipping interests has been asked. We have nothing to alter; we have no further concession to make. What then, gentlemen, is the use of further discussion? The honorary member representing the Chamber of Commerce said a new factor had been introduced by the lesson we received in the last typhoon. Are we to await more lessons from more typhoons? Are we to sacrifice more lives before we make up our minds what we are going to do in this matter?

He said also that there was a new aspect on account of constantly changing personnel of Hong Kong. Will waiting bring us any nearer our end from what point of view? Are we to wait for fresh changes, fresh arguments and fresh men? As I said before, gentlemen, I think any further postponement would be nothing more or less than culpable vacillation. We have got to do this thing, and we should make up our minds to do it at once.

The resolution was carried by a vote of ten to two.

On August 29, 1909, Berkeley moved to read a Bill entitled *An ordinance (No. 39 of 1909) to authorize the construction and maintenance of a harbour of refuge upon and over certain portions of the sea bed and foreshore situated upon the harbour frontage at Ta Kok Tsui, Mong Kok Tsui, and Yaumarti, Kowloon.* The Bill was finally read the third time and passed on March 11, 1911.

Towards the end of 1909, the dredging in the typhoon shelter at Causeway Bay was completed. A contractual work of the new typhoon shelter at Mong Kok Tsui was signed on October 27, 1910 with a contract price of \$2,018,002. The contract time for completion of the new shelter would be October 20, 1915. The actual construction of the new typhoon shelter began in January 1911. However, the dredging in the harbour frontage at Tai Kok Tsui, Mong Kok Tsui, and Yaumarti was already begun in 1909.

Lugard completed his term as the governor in March 1912. On November 20, 1913, the Executive Council announced that the regulations for the Harbours of Refuge in Table X of the schedule to the Merchant Shipping Ordinance, 1899, were repealed and substituted by the revised Table X for the Harbour of Refuges at Causeway Bay and Yaumarti Bay.

The financial statements in the government *Gazette* showed that the work on the Yaumarti typhoon shelter continued steadily between 1911 and 1914. Finally on December 16 1915, May commemorated the completion of the Yaumarti typhoon shelter by laying a stone at the southern end of the detached breakwater.

The construction of typhoon shelters has gradually become a common practice in dealing with however short the typhoon warning might be. Since 1915, twelve new typhoon shelters were built in Hong Kong: Aberdeen, Sam Ka Tsuen, Shaukeiwan, Shuen Wan, Yim Tin Tsai, Chung Chau, Kwun Tong, Rambler Channel, To Kwa Wan, Tuen Mun, Hei Ling Chau, and Chi Wan.

#### v. Planting the seed for the current tropical cyclone warning system

On September 18, 1906, a violent storm hit Hong Kong. At 0800 hours, the Observatory hoisted a black drum when the surface wind was 37 kts. Within 10-15 minutes, a typhoon gun was fired. By 1000 hours, the surface wind increased to 67 kts.

The loss of human lives and properties were devastating. The public outcry railed against the late and insufficient warning. Worst, on September 19, Hong Kong Daily Press stated: "the public will not be satisfied unless there is an exhaustive enquiry held touching the whole conduct of this department." On September 24, Nathan ordered an enquiry if the earlier warning of the storm could have been given to shipping.

At a Legislative Council meeting on September 27, 1906, Hewett brought up the subject concerning the service of the Observatory:

I do not hold with the cry, which has unfortunately been raised too often, that the Observatory is altogether in the wrong. I do not refer to the storm of the 18<sup>th</sup> instant, as the subject is sub judice, The Committee of the Chamber of Commerce have in days passed felt it to be their duty to point out that they considered they did not always receive the assistance which the shipping was entitled to receive from the Observatory. This resulted in the inquiry held twelve years ago, which exonerated the Observatory. I do not wish to exonerate or to blame, but there is no question that there is a strong feeling in the community that thought a little want of friendliness or reciprocity on the part of some of the officials. We have not had the fullest possible benefit from the Observatory, which we are entitled to expect.

Responding to the criticisms from the Legislative Council members concerning about the administration of the Observatory, Nathan asked the Council members if the scope of the enquiry should be extended to cover the administration of the Observatory. The public opinion prevailed that the lack of cooperation with the Observatories of Manila and Shanghai detracted the efficiency of the Observatory.

#### Ho replied:

I may say the unofficial members are all agreed that the scope of the inquiry should be extended. I think the general feeling is that not only should the facts as to whether notice could have been given sooner or later should be ascertained, but that an inquiry should be conducted into the general management of the Observatory and its relations with other stations in Manila and Shanghai,

whether the relations are of such a cordial nature as to enable the Observatory here to receive proper warning of approaching typhoons. So far as I know, the opinion of the unofficial members is in favor of the committee being extended.

Nathan authorized the scope of inquiry be extended. Also, a report would focus on the question if the earlier warning of the storm could have been given to shipping. A second report would address the more general questions.

Heading the enquiry was a committee of four members: Berkeley, Skottowe, Butterworth, and Sommerville. A total of 10 persons, including the observatory staff (Doberck and Figg), marine captains, and the French Counsul, either testified before the committee or submitted written testimonials over four days

The report on the finding was issued on October 23, 1906. The committee concluded that prior to 0744 hours on the September 18, 1906 there was no indication of typhoon approaching Hong Kong. The warning, by hoisting the black drum on the morning of the September 18, 1906, was given as soon as, in the circumstances, was practically possible.

The discussion of the storm of September 18, 1906 here was beyond the scope of the present study. However, the testimonials given by interviewees revealed several public views. First, several commercial sectors did not have high regard with the Observatory about the storm warning system as Figg complained that these several commercial sectors attempted to influence public opinion against the Observatory on the basis that other observatories forecasted the progress of the storm of September 18.

Second, Outerbridge stated that cooperation between the Observatory and Manila Observatory was not cordial. Although Outerbridge did not offer any evidence, the incidents surrounding the typhoon of September 6, 1893 and the typhoon of October 5, 1894 gave a glimpse on the cooperation between the two observatories (Bergholz, 1899). In both cases, the press severely criticized the Observatory for ignoring or being slow in reacting to the storm advisories from the Manila Observatory. To make the situation worse was in the case of the typhoon on September 6 1893; a telegram clerk mutilated the advisory from the Manila Observatory during the process several days before the typhoon struck Hong Kong. Then others accused Manila Observatory for not telegraphing the advisory to Hong Kong. The Spanish Consul in Hong Kong needed to explain the matter by retelling what was reported in the press from Philippines. To end the controversy, the telegraph office sent a message and confirmed that the advisory had been mutilated.

Third, the local warning signal was not effective in informing the public of the local gales. From the moment the black signals (non-local signal) were hoisted to the moment the typhoon gun (local signal) was fired; frequently the notice of a typhoon warning was short. To allow the native vessels to proceed to a shelter in a short notice and subsequently to minimize the loss of life, harbour property and infrastructure, the public and the Government were willing to accept the construction of typhoon shelters at various sites in Hong Kong as a new, practical remedy.

The committee did not recommend what new course the Observatory should take; presumably a second report would address that question. In any case, the enquiry impelled the Observatory to seek a new era of cooperation particularly with Manila Observatory, Zi Ka Wei Observatory, and Formosa Weather Service in exchanging meteorological information and typhoon advisory so that prompt and

sufficient warning would be given to the public. More important, the new era of cooperation set up the stage that the observatories in the Far East would consider the possibility to adopt unified warning codes as well as the improvement of warning signals.

Doberck retired in September 1907, and Figg succeeded Doberck as the Director of the Observatory. At the request of the Hong Kong Government, Figg visited Manila Observatory in the spring of 1909. Algue showed Figg the facility, equipment, and work routines at the Manila Observatory.

#### b. 1917 - 1919

On June 15, 1917, the Observatory announced that the new local and non-local storm signal codes would become effective on July 1, 1917. Several reasons promoted such a change.

Prior to 1917, the signals, displayed at Kowloon Point, showed the mariners and local residents the distance and position of a typhoon from Hong Kong while the signals displayed at the Signal Hill showed the visiting mariners the less accurate position of a typhoon relative to a landmark in the South China Sea. Therefore, it was natural to combine these signals into one set of non-local signals aiming to give a more accurate position and other information of a distant typhoon.

Second, the local warning signal, whether if it was the firing of a gun or the detonation of a bomb, frequently gave late and insufficient warning because the local warning signals were used whenever the local wind might increase to a full typhoon wind force. Therefore, a set of new signals was created in order to provide the local residents sufficient lead-time to reduce vulnerability.

Third, the use of wireless telegraphy to exchange the meteorological information instantly between the Observatory and vessels made it possible to allow some realistic lead time when local gales would arrive.

Lastly, in his annual report of 1917, Claxton stated that the introduction of the new local and non-local storm signal was to meet the urgent need of an improved service of storm warnings.

#### i. Non-local warning system

In the non-local warning system, the signals were made of ten symbols, which corresponded to ten (0-9) numerals. The system included the position of the center of a typhoon in degrees of latitude and longitude (given by 4 symbols at one yard-arm), and the direction and velocity of motion, and the time (given by 3 symbols at the other yard-arm). The non-local warning system would give a more precise, geographical location of the typhoon and the direction of movement. A more detail of this code will be given later.

In addition, the Observatory sent the non-local warning to the ports at Sharp Peak, Swatow, Amoy, Santuao, Macao, Canton, Wuchow, Pakhoi, Hoihow, Phulien, Manila, Labuam and Singapore.

#### ii. Local warning system

The local warning system consisted of seven signals (Figure 3). Signal no. 1 (a red cone) signified a typhoon that might possibly cause a gale at Hong Kong within 24 hours. Signal no. 2 to no. 5

indicated expected gales coming from directions centering on the four cardinal directions. Signal no. 6 denoted that gale was expected to increase. Signal no. 7 indicated that wind of typhoon force expected in any direction. When signal no. 7 was hoisted, three explosives bombs were set off at an interval of 10 seconds at the Water Police Station and the Harbour Office.

#### According to the Observatory,

The object of the code is to give at least 24 hours warning of a gale (Force 8 by Beaufort Scale, or 40-45 mph, mean velocity by Dimes Anemometer) and also warnings of expected changes in the direction and force of wind. Owing however to the uncertain movements of typhoons and to insufficient telegraphic observations, it will occasionally happen that signals 5 to 8 may be displayed without a gale occurring at Hong Kong, or even Gap Rock, but the reverse is not likely to happen, except in the case of typhoons forming in the vicinity and traveling rapidly towards Hong Kong, or of a located typhoon increasing its rate of progression abnormally.

Figure 3. Hong Kong Storm Signal Code (Local), 1917.

Signal No.	Symbol	Meaning
1	Red <b>下</b>	a typhoon exists which may possibly cause a gale at Hong Kong within 24 hours
2	Ð	gale expected from the north (NW to NE)
3	<b>\$</b>	gale expected from the south (SE to SW)
4	*	gale expected from the east (NE to SE)
5	•	gale expected from the west (NW to SW)
6	<u> </u>	gale expected to increase
7	69	wind of typhoon force expected (any direction)

Signal No. 7 will be accompanied by three explosive bombs, fired at intervals of 10 seconds at the Water Police station and repeated at the Harbour Office.

Night Signals (lamps)

Signal No.	Lights	
1	White White White	
2	White Green Green	
3	Green White White	
4	Green Green White	
5	White White Green	
6	Green Green Green	
7	Red Green Red	

Signal No. 7 will be accompanied by explosive bombs as above, in the event of the information conveyed by this signal being first published at night.

On December 31 1926, a red T replaced the red cone as the signal no. 1.

The local warning system of 1917 did not make any reference to shipping nor navigation. The signals would show the information of local gales and directions of the expected gales at Hong Kong. Therefore, it was intended for the local residents, including the boat population and also visiting mariners.

From this time onwards, the core of the local warning system of 1917, which remained to provide the information of directions of the local gale, marked the origin of the present tropical cyclone warning system.

The signals were hoisted at the masthead of the storm signal on Blackhead Hill, Green Island, Harbour Office, H. M. S. Tamar, the flagstaff on the buildings of the Hong Kong Kowloon Wharf and Godown Company at Kowloon, the flagstaff on the buildings of standard Oil Company at Lai Chi Kok, and the flagstaff near the Field Officer's Quarters at Lyemun.

Moreover, when local signals were hoisted in the Victoria Harbour, supplementary warnings, given by a cone, would be displayed at Aberdeen, Gap Rock, Sai Kung, Sau Ki Wan, Sha Tau Kok, Stanley, Tai Po, and Waglan Island. These signals were hoisted for the benefits for the local and passing ocean vessels.

Because signal no. 2 to signal no. 5 indicated that gale would come from a certain direction, the new night signals were designed with four principles.

- (1) That red shall indicate the greatest danger and white the least.
- (2) That of the two upper lights: white shall represent west and green east.
- (3) That the top light shall indicate the first of two directions.
- (4) That were possible, the signals (2) and (3), for the bottom light, green shall represent north and white south.

Using these four principles, the night signals were shown in Fig 3. When the revised night signals were introduced, the lights for signal no. 7 were Red Red Red. It was changed to Red Green Red on June 22, 1917. Note that night signal no. 1, night signal no. 6, and night signal no. 7 were non-directional. Night signal no. 5 did not follow any of the four principles because it was limited by the availability of the given color.

#### iii. A new definition for gale

On January 1, 1918, the Observatory redefined the wind force in signifying the gale condition in the new local warning system. Prior to 1918, five catalogues defined the wind force: light, moderate, fresh, strong, and gale, which were quantified by miles per hour. For instance, gale referred to wind that blew at 40 miles per hour at Gap Rock. In the new system, the same five catalogues defined the wind force, but Beaufort scale quantified them. For instance,

utort Scale
3
5
6
7

Gale would occur when the wind attained force 8 at Gap Rock, Waglan Island, or Hong Kong.

#### 5. Discussion

In order to meet the demand of shipping between 1900-1919, the Observatory introduced two sets of warning code. In the first set, the Observatory continued to use a system of drum and ball in providing the probable location of a storm to the residents in the territory and also mariners who were about to leave the harbour. In the second set, the Observatory adopted the China Coast Codes of the Zi Ka Wei Observatory. The China Coast Codes would indicate the rough location, movement, and intensity of a storm within in the China Seas. By using the China Coast code in Hong Kong, the original proposal of 1881 was fulfilled such that the ports along the China coasts would use one uniform set of warning codes.

Both sets of code did not indicate that bad weather would be immanent. The Observatory used the urgent signal to warn the public when local gales would be expected.

The shipping community found the red signals serious disruption to shipping work inside the harbour. The native mariners terminated their work and ran for the shelter as soon as the red signals were hoisted. Therefore, the Chamber of Commerce urged the Government to abolish the red signals on several occasions.

The storm in September 1906 and the subsequent inquiry led to several positive changes. First, it compelled the Observatory to seek new ways to improve the local warning. The use of wireless telegraphy to exchange the meteorological information instantly between the Observatory and vessels made it possible to allow some realistic lead time when local gales would arrive. Therefore, in 1917, the Observatory introduced a new local warning system in which the signals now indicated directions of gales over the territory. The system of local warning signal in 1917 marked the origin of the current warning system.

To benefit the mariners in the Far East, the Observatory sought a new era of cooperation with other observatories in the Far East, and the cooperation would lead to consider a new uniform system of warning codes for the Chine Seas. To benefit the floating population in the territory, the public and government began to support the construction of typhoon shelters in various locations in the territory in order to deal with however a short notice of the typhoon warning might be so that sufficient time would always be given to boats to proceed safely to a refuge.

#### Acknowledgments

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Finally, Y. K. Chan has provided invaluable suggestion and editorial assistance making the manuscript into the final form suitable for publication. Thank you, Y. K.

#### Appendix I. Biographical Notes

Algue, J., Director (1897-1926), Manila Observatory, Philippines.

Berkeley, H. S., Barrister, Attorney General (1902 -1909), Unofficial Member of the Legislative Council (1908); Unofficial Member of the Executive Council (1908); Committee member of the enquiry on the earlier warning of the typhoon of September 18, 1906, Hong Kong.

Blake, H. A., Governor (1898-1903), Hong Kong.

Bowen, G. F., Governor (1883-1885), Hong Kong.

Butterworth, H., Royal Navy, committee member of the enquiry on the earlier warning of the typhoon of September 18, 1906, Hong Kong.

Chatham, W., Director of Public Works (1901-1920), Hong Kong.

Claxton, T. F., Director (1912-1932), Royal Observatory, Hong Kong.

Denison, practical engineer, designed the typhoon shelter off the Kennedy Town, Hong Kong, 1903.

Dickson, C. W., Partner in the firm of Jardine, Matheson and Co., Deputy Chairman of the Hong Kong and Shanghai Banking Corporation. Unofficial Member of the Legislative Council (1902-1906), Unofficial Member of the Executive Council (1902-1906), Hong Kong.

Doberck, W., Director (1884 - 1907), Hong Kong Observatory, Hong Kong.

Figg, F. G., First Assistant to Doberck (1884 -1907); Director (1907-1912), Hong Kong Observatory, Hong Kong.

Froc, L., Jesuit, Director (1902 -1930), Zi Ka Wei Observatory, Shanghai, China.

Gresson, W. J., of Jardin, Matheson & Co., Unofficial Member of the Legislative Council (1904, 1906-1910), Unofficial Member of the Executive Council (1904, 1905, 1908), Hong Kong.

Hart, R., first Inspector General (1863 -1911), Chinese Maritime Custom Service, China.

Hewett, E. A., Superintendent, P. & O. Steam Navigation Co., member of the Shanghai Municipal Council (1897-1901) and its Chairman in 1900-1901, Chairman of the Hong Kong Chamber of Commerce (1903), Unofficial Member of the Legislative Council (1906-1915); Unofficial Member of the Executive Council (1906-1915), Hong Kong.

Ho, K., Unofficial Member of the Legislative Council (1890 -1914), Hong Kong. Hunter, H. E. R, Chairman of Typhoon Relief Fund Committee (1906), Hong Kong.

Leigh, who wrote about the need of a second typhoon shelter in 1903, Hong Kong.

Lugard, F. J. D, Governor (1907-1912), Hong Kong.

May, F. H., Supertendent, Hong Kong Police (1893-1902), Secretary of Hong Kong (1902-1910), Acting Governor (1903 and 1907), Governor (1912-1919), Hong Kong.

Nathan, M., Governor (1904 - 1907), Hong Kong.

Osborne, E., Secretary of the Hong Kong and Kowloon Wharf and Godown CO. (1861), with P. & O. Steam Navigation CO. in London and Hong Kong (1880-1889), Director of Hong Kong Hotel, Dairy Farm, Steam Laundary, among others. Unofficial Member of the Legislative Council (9106-1907, 1907-1913), Hong Kong.

Outerbridge, A. W., marine captain; a witness in the enquiry on the earlier warning of the typhoon of September 18, 1906, Hong Kong.

Pollock, H. E., Barrister-at-Law, Unofficial Member of the Legislative Council (1896, 1903-1941), Unofficial Member of the Executive Council Member (1911, 1912, 1921-1941), Hong Kong.

Rumsey, R. M., Harbour Master (1891-1903), Hong Kong.

Skottowe, A. B., Superintendent, Eastern Extension Telegraph, Co., committee member of the enquiry on the earlier warning of the typhoon of September 18, 1906, Hong Kong.

Sommerville, A., marine captain, committee member of the enquiry on the earlier warning of the typhoon of September 18, 1906, Hong Kong.

Stewart, G., of Hong Kong Bank, Exchange Broker, Chairman of the China Association, Unofficial Member of the Legislative Council (1903, 1904-1907), Hong Kong.

Taylor, B. R. H., Harbour Master (1902-1908), Hong Kong.

Thomsett, H. G., Harbour Master (1873 - 1891), Hong Kong.

Thomson, A. M., Government Treasurer (1908-1911), Hong Kong.

Tyler, W. F., British Navy Captain, Coastal Inspector (1903-1918), the Chinese Maritime Custom Service, China.

Wei, Y., Unofficial Member of the Legislative Council (1896-1914), Hong Kong.

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## Society Events

'Dancing with Clouds' – Painting and Three-dimensional Art Competition organized by the Hong Kong Meteorological Society in collaboration with the Hong Kong Society for Education in Art (article published in Chinese only)

# 香港氣象學會主辦 香港美術教育協會協辦 「與雲共舞」 繪畫比賽(小學組)及立體創作比賽(中學組)

爲了推廣小學及中學生對氣象科學的興趣與認識,香港氣象學會繼 2004 年的「風之足印」小學生繪畫比賽之後,在 2005 年再次舉辦「與雲共舞」繪畫比賽(小學組)及立體創作比賽(中學組),讓同學們利用畫筆或模型創作來表達他們心中對雲的印象。

比賽反應熱烈,吸引了超過30間學校逾750位同學參加,是次評判團包括香港氣象學會及香港美術教育協會幹事,評判團於2005年7月11日選出繪畫比賽(小學組)冠亞季軍作品及優異獎共21名,同時亦選出立體創作比賽(中學組)冠亞季軍作品及優異獎共4名。中間彩頁便是得獎作品。

## Presentation of Zhu Kezhen Prize (竺可禎獎)

Every year the Society calls for nominations from undergraduates and postgraduates to compete for the Zhu Kezhen Prize.

The Zhu Kezhen Prize was set up in 1996 through a generous donation from Society Honorary member and ex-Director of the Hong Kong Observatory Mr. Patrick Sham. The prize is termed the Zhu Kezhen Prize in honour of the distinguished Chinese meteorologist, Zhu Kezhen. The first prize was awarded in 1999 and this year is the second time that the Prize has been awarded for outstanding work in the field of meteorology and related sciences.

The jury for the prize this year consisted of Dr. B.Y. Lee from the Hong Kong Observatory, Dr. K.S. Lam from Hong Kong Polytechnic University and Dr. Alexis K.H. Lau from Hong Kong University of Science and Technology.

Mr. Wong Tse Man, Ken from University of Hong Kong won the award this year for his thesis titled "Red Tides and Algal Blooms in Subtropical Hong Kong Waters, Field Observations and Lagrangian Modelling".

Mr. Wu Man Chi from the City University of Hong Kong received the award based on his research paper titled "Relationships between Summer and Winter Monsoons over East Asia" which was published in the International Journal of Climatology 2005.

The jury found the work of Mr. Wong and Mr. Wu both of high quality and usefulness and would form valuable reference of the subject concerned.

On 23 July 2005 during Annual General Meeting of the Society, our Chairman Mr. Lam Chiu-ying presented the awards to the two winners and also congratulated them on their achievements.



Society Chairman Mr. Lam Chiu-ying (middle) presenting Zhu Kezhen award certificate and prize to Mr. Wong Tse Man, Ken (right) from University of Hong Kong. Mr. Wong's advisor, Professor Joseph Lee (left), shared the joyful moment.



Mr. Lam Chiu-ying (middle) presenting Zhu Kezhen award certificate and prize to Mr. Wu Man Chi (right) from City University of Hong Kong. Mr. Wu's advisor, Professor Johnny Chan (left), was also there to congratulate on Mr. Wu's achievement.

## 「與雲共舞」繪畫比賽(小學組)冠亞季軍作品



冠軍 東華三院鄧肇堅小學 周可茵



亞軍 浸信會呂明才小學 吳嘉煥



亞軍 福榮街官立小學 畢迎春



季軍 新界婦孺福利會 梁省德學校(將軍澳) 莫素芬



季軍 天主教柏德學校 李宏皓

# 「與雲共舞」繪畫比賽(小學組)優異獎作品



大埔舊墟公立學校(寶湖道) 蔡家豪



新界婦孺福利會 梁省德學校(將軍澳) 謝彩鳳



上水惠州公立學校上午校 任頌賢



上水惠州公立學校上午校 蕭悅恩



上水惠州公立學校上午校 馮晞莛



上水惠州公立學校上午校 黃鉦軒



天水圍官立小學 潘曉霞



仁濟醫院趙曾學韞小學 莊家喬

# 「與雲共舞」繪畫比賽(小學組)優異獎作品



仁愛堂田家炳小學 羅寶程



天主教柏德學校 葉珮雯



天主教柏德學校 曾佩琳



聖公會奉基小學 廖卓瑤



聖公會奉基小學 嚴梓維



聖公會奉基小學 張萃華



福榮街官立小學 徐碧珍



聖公會阮鄭夢芹小學上午校(大埔廣福邨) 黎翹欣

## 「與雲共舞」立體創作比賽(中學組)冠亞季軍作品



冠軍 保良局董玉娣中學 曾穎文 東華三院辛亥年中學 曾曉楓



亞軍 開平商會中學 林慧懿



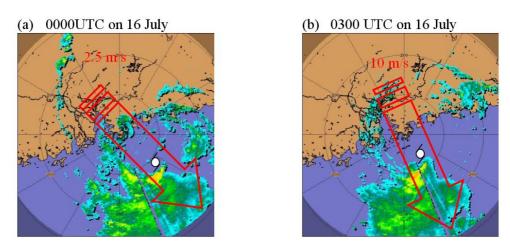
季軍 玫瑰崗學校(中學部) 關楚雲、唐溥晨、賴善美、周詠婷、 胡婉琪、鍾寶兒、吳思穎



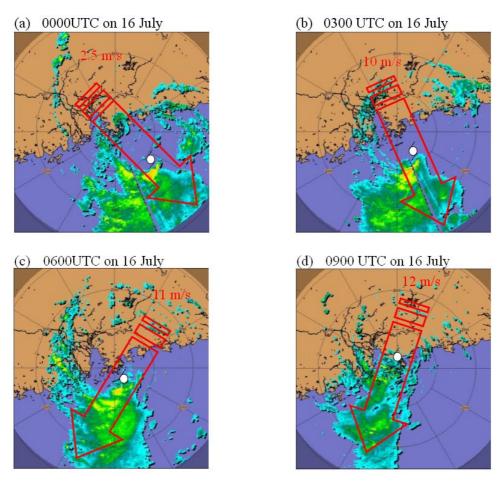
優異獎 玫瑰崗學校(中學部) 麥慧敏、翁麗萍、楊舜華、蕭旭明、 林顥泓、林建才、趙寶禮、何子俊、 侯峻達、葉映萍、葉映娜、吳庭昕

## **COLOUR PLATE**

Figure C1. Convective activity near the centre of Kompasu as shown on 3 km CAPPI radar imageries 10 hours before landfall (a), and just before landfall (b).



Convective activity near the centre of Kompasu and vertical wind shear as shown on 3 km CAPPI radar imageries on 16 July. Red arrow and figure in red indicate the vertical wind shear direction and its magnitude respectively.



## Projected Change in Hong Kong's Rainfall in the 21st Century

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#### 1. Abstract

By downscaling rainfall forecasts made by global climate models, it was found that due to global warming, the annual rainfall in Hong Kong would increase at a rate of about 1% per decade in the 21<sup>st</sup> century, about the same as in the previous 120 years. In the last 10 years of this century, that is, in the years 2090-2099, the annual rainfall at the Hong Kong Observatory (HKO) Headquarters is expected to be about 2430 mm, or 216 mm above the 1961-1990 average of 2214.3 mm.

In addition, the year-to-year variability in rainfall would also increase. In the 21st century, it is expected that there will be 6 years with annual rainfall exceeding 3343 mm, the highest rainfall recorded at HKO Headquarters in the past 120 year, and 3 years with annual rainfall less than the lowest of 901 mm. Also, from the 30-year period 1961-1990 to the last 30 years of this century, that is, 2070-2099, the number of days in a year with hourly rainfall exceeding 30 mm will increase from about 5.6 to 6.5.

#### 2. Introduction

The Intergovernmental Panel on Climate Change (IPCC) concluded in its Third Assessment Report that the global mean surface temperature has increased by  $0.6 \pm 0.2$ °C in the 20th century, and might increase by a further 1.4°C to 5.8°C before the end of 2100 depending on the emission scenario (IPCC 2001). The report also pointed out that in association with this global warming, the global average precipitation would increase and larger year to year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected. Enhancement in the water cycle associated with global warming is a likely reason for the projected increase in global precipitation.

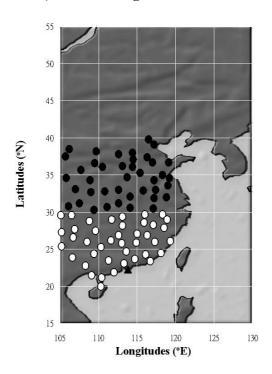
For Hong Kong, using the statistical downscaling method, Leung *et al.* (2005) showed that under the influence of global warming, in the last decade of this century the annual mean temperature in Hong Kong could rise by 1.7°C to 5.6°C above the 1961-1990 normal. The present study is an attempt to project the change in rainfall in Hong Kong up to the end of the century using this statistical downscaling method. The parameters examined are annual rainfall, the number of rain days, viz., days with more than 0.1 mm of rainfall, and the number of heavy rain days, viz., days with hourly rainfall greater than 30 mm which is one of the criteria for issuing the Amber Rainstorm Warning.

#### 3. Data

Historical rainfall data and rainfall forecasts made by global climate models are used in this study. The historical rainfall data used are the monthly rainfall recorded between 1951 and 2000 at the

HKO Headquarters, 41 stations in southern China (area bounded by 20-30°N, 105-120°E) indicated by white dots in Figure 1, and 40 in central China (area bounded by 30-40°N, 105-120°E) indicated by black dots in Figure 1. The data were sourced from HKO and the National Climate Centre (NCC) of the China Meteorological Administration (CMA).

Figure 1. Location of the Hong Kong Observatory Headquarters (indicated by the solid triangle) and 81 rainfall recording stations in Mainland China (indicated by dots). White dots (a total of 41) denote stations in southern China (defined as region X1:20-30°N and 105-120°E). Black dots (a total of 40) denote stations in central China (defined as region X2: 30-40°N and 105-120°E).



The rainfall forecasts used here are the gridded monthly forecasts made by the seven global climate models CSIRO-Mk2, ECHAM4/OPYC3, HadCM3, NCAR DOE-PCM, GFDL (consisting of the low resolution GFDL-R15 and the high resolution GFDL-R30), CCCma (consisting of CGCM1 & CGCM2) and CCSR/NIES. These forecasts are available from IPCC's Data Distribution Centre website <a href="http://ipcc-ddc.cru.uea.ac.uk/">http://ipcc-ddc.cru.uea.ac.uk/</a>. A summary of the parent organizations and resolutions of these models can be found in Leung *et al.* (2005). The emission scenarios under which rainfall projections are available from the Data Distribution Centre are listed in Table 1. Details of the emission scenarios can be found in Houghton *et al.* (1994) and Nakicenovic *et al.* (2000).

#### 4. Methodology

### (a) Annual rainfall

## (i) Statistical downscaling

The statistical downscaling technique is one of two techniques used to generate local and regional

scale climate projections from global climate model forecasts which are usually made at relatively low spatial resolution, typically 300 km x 300 km (e.g., Kilsby *et al.* 1998). It has become popular because of its computational economy compared with the alternative approach which is dynamical downscaling (see for example Benestad 2001, Fan *et al.* 2005), and has a level of skill on par with the dynamical approach (Murphy 1999). Rainfall and temperature are two of the variables most frequently downscaled statistically (e.g., Hanssen-Bauer *et al.* 2005). Regression is often employed in statistical downscaling (see for example Wigley *et al.* 1990, Wilby *et al.* 2005).

Table 1. Rainfall forecasts sourced from IPCC for different global climate models and different emission scenarios (shaded in light grey).

Model	Model		92a	SRES						
Model			GS	A1FI	A1B	A1T	A2	B1	B2	
GFDL	R-15				G G	· ·	(c)			
GFDL	R-30									
CCSR/NIE	CCSR/NIES									
CSIRO-Mk	CSIRO-Mk2					2				
CCCma	CGCM1						(a) (b) (c)		Cor est	
CCCIlia	CGCM2			4	ž.					
HadCM3	HadCM3		*							
NCAR DOE-I	NCAR DOE-PCM		v			,		3 7		
ECHAM4/OP	ECHAM4/OPYC3									

<sup>\*</sup> IS92a: 'Business as Usual' emission scenario. GG: cooling by sulphates not included, GS: cooling by sulphates included. SRES: Special Report on Emission Scenarios. A1FI: fossil fuel intensive, A1B: balanced fossil and non-fossil fuel usage, A1T: emphasis on non-fossil fuels; A2: most rapid population growth but comparatively slow economic and technological growth; B1: global solutions to sustainability; B2: increasing population with regional and local solutions to sustainability.

Statistical downscaling usually involves two main steps (e.g., Mullan *et al.* 2001). Firstly, an empirical relationship between a local or regional predictand, such as rainfall or temperature, and some large-scale predictors which may be sea level pressure, air temperature, geopotential height (von Storch *et al.* 1993, Kidson and Thompson 1998, Wilby and Wigley 2000) or rainfall (Widmann *et al.* 2003) is established using historical data. Secondly, global model forecasts of the selected large-scale predictors are fed into the regression equation to give projected values of the local or regional predictand.

As in the temperature projection study for Hong Kong undertaken by Leung *et al.* (2005), this study uses regression—based downscaling of the rainfall forecasts of global climate models to project the change in Hong Kong's annual rainfall to the end of the century.

A multiple linear regression relationship between annual rainfall anomaly at HKO as the predictand and two large-scale predictors, viz., the spatially averaged annual rainfall anomaly in southern China and the spatially averaged annual rainfall anomaly over central China (see Section 3(ii)) is established using historical data. The average annual rainfall anomaly over southern China is calculated from the monthly rainfall recorded at the 41 stations, and the average annual rainfall anomaly over central China from the 40 stations. The average annual rainfall anomaly over each of these two regions in the future are computed from the model grid point values and then fed into the regression equation to give the projected annual rainfall anomaly for Hong Kong.

## (ii) Selection of predictors

That two large-scale predictors - spatially averaged rainfall over southern China and over central China - are needed is because of the very clear out-of-phase relationship in the annual rainfall anomalies in these two regions. When southern China has more than normal annual rainfall, central China would usually have lower than normal annual rainfall and vice versa (e.g., Dai *et al.* 1997).

## (iii) The multiple linear regression equation for annual rainfall

The multiple regression equation for annual rainfall anomaly at HKO Headquarters y is

$$y = 2.05x_1 - 1.79x_2 + 19.14 \tag{1}$$

where  $x_1$  is the spatial average of rainfall anomalies in southern China, and  $x_2$  the spatial average of rainfall anomalies in central China (Figure 2). The coefficient of determination  $R^2$  is 0.42. That is, the proportion of variation in the annual rainfall anomaly at HKO Headquarters accounted for by the regression is 42% (Wilks 1995).

#### (b) Extreme annual rainfall

The usual way of classifying extreme values is to use two standard deviations as boundary (e.g., Palmer and Räisänen 2002, Wang and Xu 1997). Adopting this classification and using the mean and standard deviation in the period 1961-1990 lead to an annual rainfall greater than 3239 mm as extremely high annual rainfall, and an annual rainfall less than 1189 mm as extremely low annual rainfall. Furthermore, the absolute maximum and minimum annual rainfall for the 120 years of record were 3343 mm and 901 mm respectively. The annual rainfall for each model and for each scenario is first found as in (a) and the number of years with annual rainfall outside the above thresholds is counted.

#### (c) Number of rain days and number of heavy rain days

The projected number of rain days per year  $N_r$  is derived from the projected annual rainfall y. The linear regression equation, constructed from the number of rain days and annual rainfall observed at HKO Headquarters, is

$$N_r = 0.019 \ y + 95.6$$
 (2)

The coefficient of determination  $R^2$  is 0.35, or 35% of the variation in the number of rain days  $N_r$  is accounted for by the regression.

Projection of the number of heavy rain days  $N_h$ , viz., the number of days with hourly rainfall exceeding 30 mm is similarly made. The regression equation is

$$N_h = 0.0035 \quad y \quad - \quad 2.04 \tag{3}$$

The corresponding coefficient of determination  $R^2$  is 0.44. Thus some 44% of the variation in  $N_h$  is accounted for by equation (3).

Multiple linear regression surface

Multiple linear regression surface

1500

-250

Annual rainfall anomaly in region X2 (mm)

Figure 2. Multiple linear regression of the annual rainfall anomaly in Hong Kong with that in southern China (X1) and in central China (X2).

#### 5. Results and Discussions

#### 5.1 Past rainfall trend

Rainfall record at HKO Headquarters dated back 120 years to 1885. As shown in Figure 3, the annual rainfall at the HKO Headquarters has a rising trend of 20 mm (that is about 1%) per decade between 1885 and 2004, though this trend is not statistically significant at 5% level. Between 1947 and 2004, the trend is higher at 43 mm per decade, but it is again not statistically significant at 5% level. In the past 120 years, the annual rainfall lies between 901 mm and 3343 mm. The 1961-1990 normal of annual rainfall is 2214.3 mm.

in region X1 (mm)

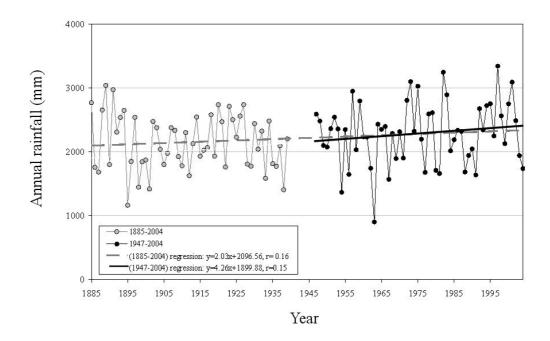
#### 5.2 Projected changes in rainfall

#### (a) Annual rainfall

Table 2 and Figure 4 give the projected annual rainfall in Hong Kong, which varies with the scenario and the model.

For the scenario IS92a GG, Figure 5 shows little change in the multi-model ensemble mean annual

Figure 3. Time series of the annual rainfall in Hong Kong. Both linear trends shown are not significant at the 5% level.



rainfall anomaly in the 21<sup>st</sup> century. The multi-model ensemble mean annual rainfall anomaly is generally negative in the emission scenario IS92a GS but positive in the SRES. Lai and Harasawa (2001) noted that if sulphate aerosols are added in the climate model simulation experiments, the rainfall in Asia will decrease. It was also mentioned in IPCC (1998) that when both the increase in greenhouse gases and sulphate aerosols are considered, the temperature difference between land and sea in the Asian monsoon region would decrease. Hence the monsoon would weaken and its associated rainfall would become less. For all scenarios, the multi-model ensemble mean annual rainfall anomaly is positive and also has a rising trend (Figure 5d).

In the 30-year period 2070-2099, 20 out of 24 (i.e. 83%) different scenarios and models combinations forecast the annual rainfall anomaly to be positive, despite all forecasting positive annual mean temperature anomalies (Figure 6).

Focusing on the models, the difference in simulation results between CCSR/NIES and CCCma is the largest (Table 3). Projected annual rainfall anomalies from CCSR/NIES in the eight emission scenarios are all positive, and also higher than those of other models in the same scenarios. The forecasts by CCCma are negative in most of the scenarios in contrast to the positive values from other models. This difference in model forecasts is possibly related to the limited skill of CCCma in simulating the present Asian climate (Lai and Harasawa 2001).

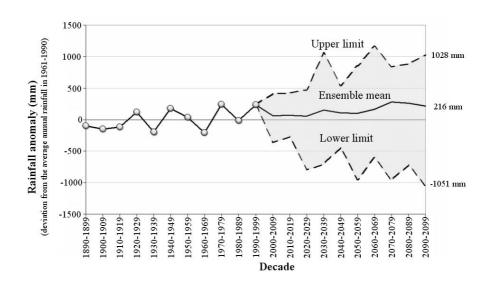
Except IS92a GS, the multi-model ensemble mean annual rainfall anomalies are positive for different emission scenarios (see Table 3). This reflects that the increase in annual rainfall of Hong Kong is in line with the increase in the concentration of carbon dioxide. Past model simulation studies have already revealed that the rainfall in East Asia and China would increase under the scenario of doubled carbon dioxide concentration (Zhao *et al.* 2005).

Table 2. Projected change in annual rainfall in Hong Kong. The change is with reference of the 1961-1990 normal.

Scenario		Model		year	30-year			
		10100461	2040-2049	2090-2099	2010-2039	2040-2069	2070-2099	
		GFDL-R15	285.0		0.7			
	GG	CCSRANIES	-220.5	146.6	1403	189	261.0	
		CSIRO-Mk2	1393 71.7		283	284.9	228.0	
189	66	CCCma CGCM1	96.7	-18.6	313	-1703	1249	
		HadCM3	-188.1	513.7	-1369	-183.4	188.4	
·		ECHAM4/OPYC3	-1552	-5643	-53.4	-232.4	-287.2	
1935		GFDL-R15	-98.8		-160.4			
		CCSRANIES	-2623	129.4	109.4	-120.8	159.1	
	l	CSIRO-Mk2	-33.5	-32.2	439	-56.0	139.9	
	GS	CCCma CGCM1	-449.5	-1051.2	-488.4	-669.7	-884.2	
		HadCM3	105.8	-333.7	123.7	40.1	121.0	
	ECHAM4/OPYC3	14.0		-64.8				
A	A1FI A1B	CCSRANIES	300.1	4163	51.1	191.8	610.4	
3,		CCSRANIES	534.4	882.1	415.6	6693	738.5	
1		CSIRO-Mk2	473.1	382.0	1853	538.6	584.2	
I	AlT	CCSR/NIES	318.1	1028.4	269.8	438.4	786.2	
		CCSRANIES	250.6	628.7	281.1	388.2	6703	
	A2	CSIRO-Mk2	439.3	425.2	2969	363.5	667.6	
	A2	CCCma CGCM2	-305.4	-450.8	24.4	-296.5	-587.6	
		HadCM3	-57.7	241.4	101.1	40.4	347.8	
200	ві	CCSRANIES	276.5	747.4	207.9	687.8	546.2	
	DI	CSIRO-Mk2	2503	600.8	370.4	220.4	421.9	
		GFDL-R30	-1982	191.0	973	40.7	161.0	
		CCSRANIES	351.2	968.4	598.7	788.6	742.8	
	B2	CSIRO-Mk2	462.5	602.5	2173	307.2	504.1	
	CCCma CGCM2	98.0	-655.9	-161.7	-280.4	-407.4		
		HadCM3	363.6	307.5	-3.8	105.4	2269	
		Ensemble upper limit	534.4	1028.4	598.7	788.6	7862	
		Ensemble mean	1033	215.7	93.5	129.8	252.7	
		Ensemble lower limit	-449.5	-1051.2	-488.4	-669.7	-884.2	

<sup>\*</sup> Results of NCAR DOE-PCM model are not given as the model's rainfall data from 1961-1990 are not available from the IPCC DCC website.

Figure 4. Past and projected changes in annual rainfall in Hong Kong. The change is with reference to the 1961-1990 normal.



Using the multi-model ensemble mean, the rainfall in Hong Kong would increase at a rate of about 1% per decade in the 21<sup>st</sup> century, and the trend is statistically significant at the 5% level. result is similar that obtained by **NCC** of **CMA** for Guangdong to (http://www.ipcc.cma.gov.cn/cn/MapSys/) (Figure 7). Table 4 compares the projected change in annual rainfall for Hong Kong from 1961-1990 to 2070-2099 obtained in the present study with that obtained by the Climate Research Unit (CRU) of the University of East Anglia of the United Kingdom (http://www.cru.uea.ac.uk/%7Etimm/climate /ateam/TYN CY 3 0.htm). It can be seen that the projected changes from the two studies are of the same sign for each scenario though differing in magnitude. This difference in magnitude is probably related to the difference in the downscaling method adopted. CRU has used the weighted average of projections at 0.5° resolution (Mitchell et al., 2002).

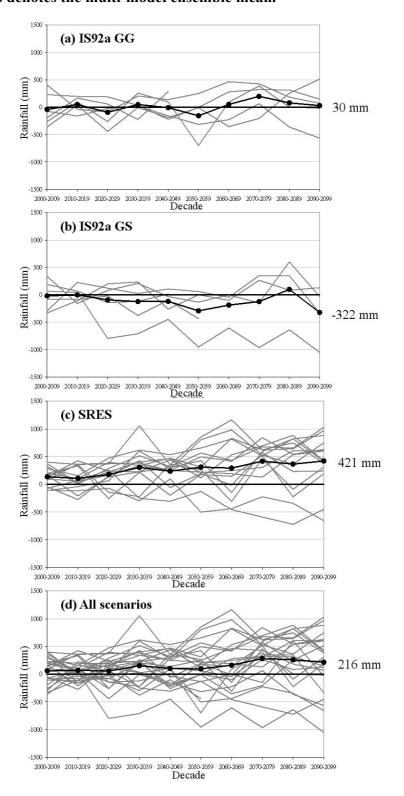
In the last 10 years (2090-2099) of this century the ensemble mean annual rainfall is 2430 mm, or 216 mm above the 1961-1990 average of 2214.3 mm (Figure 4).

#### (b) Extreme annual rainfall

The multi-model ensemble mean number of years in which extremely high annual rainfall and extremely low annual rainfall would occur in 30-year periods in the 21<sup>st</sup> century are shown in Figure 8. It can be seen that the ensemble mean number of years with extremely high annual rainfall rises from 1 in 1961-1990 to 4.6 (i.e. about 4 to 5) in 2070-2099. On the other hand, the number of occurrence of extremely low annual rainfall is expected to rise from 1 in 1961-1990 to 1.8 (i.e. about 2) in 2070-2099.

In the past 120 years, the highest and lowest annual rainfall recorded at HKO Headquarters was 3343 mm and 901 mm, respectively. In the 21<sup>st</sup> century, the multi-model ensemble mean number of occurrences of annual rainfall above 3343 mm is 5.7 (i.e. about 6), while the number of occurrences of annual rainfall below 901 mm is 2.9 (i.e. about 3).

Figure 5. Projected changes in annual rainfall in Hong Kong based on different models under (a) IS92a GG, (b) IS92a GS, (c) SRES and (d) all scenarios. Rainfall change is with reference to the 1961-90 normal. The dark line joining the black dots denotes the multi-model ensemble mean.



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Figure 6. Projected changes in 30-year mean annual rainfall and annual mean temperature in Hong Kong from 1961-1990 to 2070-2099 for different emission scenarios. Crosses represent projected changes based on different models under various scenarios. The black dot denotes the ensemble mean of all available scenarios and models.

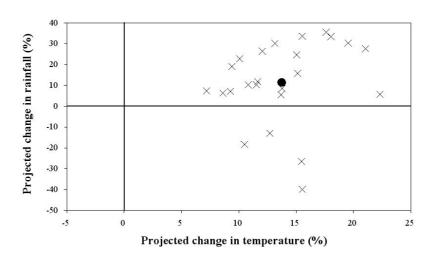


Table 3. Projected change in 30-year mean annual rainfall from 1961-1990 to 2070-2099 for different climate models and for different emission scenarios. Scenarios are ranked according to the atmospheric carbon dioxide concentration from low to high, SRES B1 being the lowest and SRES A1FI the highest.

Scenarios	lowes	lowest						ighest	Scenario	
Model	SRES				IS92a		SRES		mean	
	B1	A1T	B2	A1B	GG	GS	A2	A1FI		
CCSR/NIES	546.2	786.2	742.8	738.5	261.0	159.1	670.3	610.4	564.3	
CSIRO-Mk2	421.9		504.1	584.2	228.0	139.9	667.6		424.3	
HadCM3			226.9		188.4	121.0	347.8		221.0	
CCCma CGCM1/2			-407.4		124.9	-884.2	-587.6		-438.6	
ECHAM4/OPYC3					-287.2				-287.2	
GFDL-R30			161.0						161.0	
Model mean	484.1	786.2	245.5	661.4	103.0	-116.1	274.5	610.4	252.7	

#### (c) Number of rain days

The number of rain days projected using Equation (2) are listed in Table 5. It can be seen that in 2070-2099, the multi-model ensemble mean number of rain days in a year is 142, slightly higher than the 137 days for 1961-1990.

Figure 7. Projected changes in annual rainfall in Hong Kong and in Guangdong in the 21st century (% increase per 100 years). Trends for Guangdong are obtained from http://www.ipcc.cma.gov.cn/cn/MapSys/.

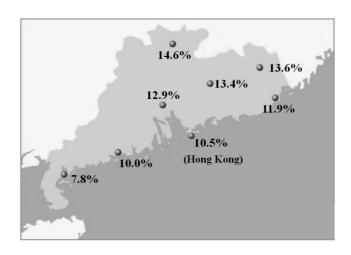


Table 4. Comparison of the projected change in 30-year mean annual rainfall in Hong Kong from 1961-1990 to 2070-2099 obtained in the present study with that obtained by the Climate Research Unit (CRU) of the University of East Anglia.

Model	Scenario	Present study	CRU
	A2	667.6	312.7
CSIRO-Mk2	B1	421.9	288.6
	B2	504.1	265.7
CCCma CGCM2	A2	-587.6	-93.5
CCCIIIa CGCWIZ	B2	-407.4	-152.8
HadCM3	A2	347.8	386.9
HauCM3	B2	226.9	377.1

## (d) Number of heavy rain days

The number of heavy rain days projected using equation (3) is also given in Table 5. It can be seen that the number of days in a year with hourly rainfall greater than 30 mm will increase from the 1961-1990 average of 5.6 to 6.5 in the period 2070-2099.

#### 6. Conclusion

Statistical downscaling of rainfall forecasts made by global climate models shows that under the influence of global warming, annual rainfall in Hong Kong would increase at a rate of about 1% per decade in the 21<sup>st</sup> century. It can be anticipated that in the years 2090-2099, the annual rainfall at HKO Headquarters would be about 2430 mm, an increase of 216 mm from the 1961-1990 average of 2214.3 mm.

Figure 8. Projected number of years with extremely low or extremely high annual rainfall in 30-year periods in the 21st century.

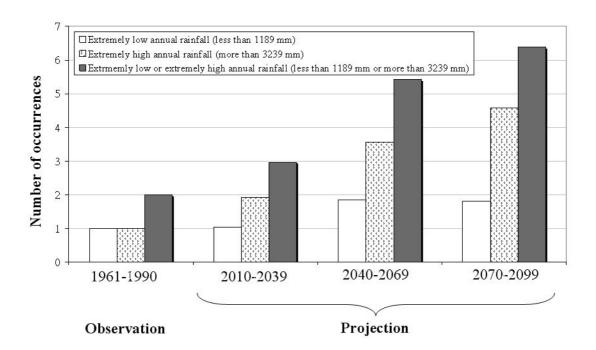


Table 5. Projected annual number of rain days and annual number of days with hourly rainfall exceeding 30 mm.

Parameters	Period		Model Ensemble						
raiameters	renod	Lower limit	Mean	Median	Upper limit	average			
Annual number	2010-2039	128.2	139.1	139.2	148.6				
of rain days	2040-2069	124.7	139.8	138.7	152.2	137.4			
(days)	2070-2099	120.7	142.1	142.0	152.1				
Annual number of	2010-2039	3.9	5.9	5.9	7.7				
days with hourly	2040-2069	3.3	6.0	5.8	8.3	5.6			
rainfall > 30 mm (days)	2070-2099	2.5	6.5	6.4	8.3	3.0			

The year-to-year variability in rainfall in Hong Kong would also increase. It is expected that in the 21st century there would be 6 years with annual rainfall exceeding 3343 mm the highest annual rainfall recorded at HKO Headquarters in the past 120 year, and 3 years with annual rainfall less than the lowest of 901 mm.

For the number of days with heavy rain, from the 30-year period 1961-1990 to the 30 years

2070-2099, the number of days in a year with hourly rainfall exceeding 30 mm will increase from about 5.6 to 6.5.

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## Changes in the Structure of Tropical Storm Kompasu (0409) Before and After Landfall over Hong Kong in July 2004

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#### 1. Introduction

Landfalling tropical cyclones pose a much more serious threat to lives and property than at sea, especially with more and more people living in coastal areas. In view of this, programmes such as WMO's International Landfalling Tropical Cyclone Programme (ITCLP, see <a href="http://www.wmo.int/web/arep/wwrp/RDPs/itclp.html">http://www.wmo.int/web/arep/wwrp/RDPs/itclp.html</a>), China's Landfalling Typhoon Experiment (CLAYTEX, see Chen et. al. 2004) and the United States' Landfalling Hurricane Programme (see Marks and Shay 1998) are some of the initiatives that have been proposed or launched to improve the understanding and prediction of tropical cyclone landfalling processes and to minimize the impacts of landfalling tropical cyclones. Some of the changes induced by land on tropical cyclones have been discussed by Kepert (2002).

In the case of Hong Kong, Cheng et al. (2000) have examined the characteristics of tropical cyclones landfalling over Hong Kong in 1999 using satellite imageries and observations from the Hong Kong Observatory's Doppler radars, wind profilers and automatic weather stations. Chan et al. (2004) have suggested that wind shear between 200 hPa and 850 hPa levels is closely related to convection asymmetries for tropical cyclones making landfall along the south China coast. The extent to which this applies to the case of Tropical Storm Kompasu, a weaker storm than those studied by Chan et al. (2004), which landed over Hong Kong on 16 July 2004 is discussed in this paper.

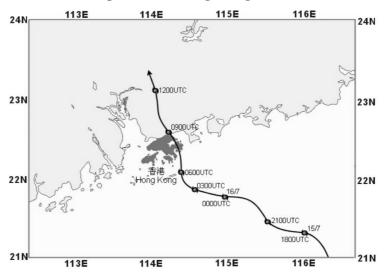
#### 2. Brief description of Tropical Storm Kompasu

Kompasu (0409) formed as a tropical depression over the western North Pacific on the morning of 14 July. It intensified into a tropical storm that afternoon. Steered by prevailing southeasterlies, Kompasu headed northwest towards the south China coast upon entering the South China Sea and made landfall over Hong Kong at about 0730UTC (3.30 p.m. local time) on 16 July. The track of Kompasu during its approach to and landfall over Hong Kong is shown in Figure 1.

At its peak intensity, the maximum sustained winds near the centre of Kompasu were estimated to be about 83 km/h, and the mean sea level pressure about 985 hPa. During its approach to and landfall over Hong Kong, a maximum hourly mean wind of 88 km/h and a maximum gust of 106 km/h were recorded at Waglan, an island about 20 km to the southeast of Hong Kong. The lowest instantaneous mean sea level recorded there was 995.7 hPa.

The rainbands of Kompasu brought heavy squally showers to Hong Kong that afternoon and the following day. More than 120 millimetres of rainfall were recorded at the Observatory Headquarters. In Guangdong, many trees were uprooted and signboards collapsed. Ferry services between Guangdong, Hong Kong and Macao were suspended.

Figure 1. The track of Kompasu over Hong Kong.



## 3. Structure of Kompasu

On approaching the south China coast, Kompasu's centre became indistinguishable on the satellite imageries (Figure 2). Its surface circulation just after landfall as observed by the Observatory's automatic weather stations is shown in Figure 3a. The low level circulations at 1 km above ground as deduced through the radial winds from the Observatory's dual Doppler radar are shown in Figure 3b. At higher levels Kompasu circulation can no longer be picked up by the radars. As can be seen, there is a westward tilt between the surface and 1 km centres (Figure 3c), with a horizontal displacement of about 8.5 km over a depth of 1 km. A similar tilting feature has been observed by Cheng et al. (2000) for Typhoon Maggie which made landfall over Hong Kong in June 1999 and by Leung et al. (2000) for the midget tropical depression which landed over Hong Kong in June 2000.

Kompasu is a small storm, the distance between its centre and the outermost closed isobar being less than 250 km in its northern semicircle. This compactness meant that its convection did not interact

Figure 2. Visible picture at 0625UTC on 16 July 2004 as captured by GOES satellite.

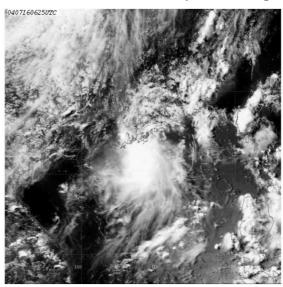
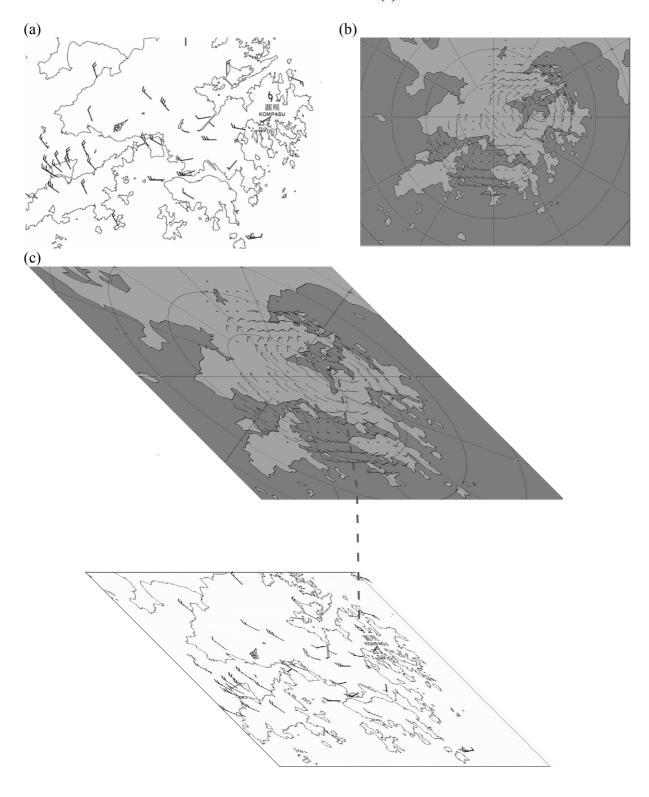


Figure 3. Surface winds recorded at various stations in Hong Kong at 0730 UTC on 16 July 2004 just after Kompasu's landfall (a), radial winds of the Hong Kong Observatory's Doppler radars 0730 UTC 16 July 2004 at 1 km (b), and 3 dimension view of the tilted centre (c).



with land until just a few hours before making landfall. As Figure C1a (in central colour plate) shows, at 2100 UTC on 15 July (5 a.m. on 16 July local time) when Kompasu was centred about 170 km over the sea areas to the southeast of Hong Kong, convection was present in all quadrants. Convection over land mostly dissipated as Kompasu interacted with land 10 hours later when Kompasu was just about to make landfall (Figure C1b, also in central colour plate), leaving the bulk of the convection over the sea in the rear left quadrant of Kompasu. The convection over land was found mainly to the front left quadrant of Kompasu, in line with the numerical results of Chan and Liang (2003).

The relationship between 200-850 hPa wind shear and the asymmetric convection of Kompasu before and after landfall is now examined. The 200-850 hPa wind shear is calculated from Operational Regional Spectral Model (ORSM)'s analysis which is available at 3 hourly intervals at 0000UTC, 0300 UTC, etc. The spatial resolution of the analysis is 20 km. Furthermore, following Chan et. al. (2004), the 200-850 hPa shear is calculated as the areal average winds within 200 km of the centre of the tropical cyclone.

The 15 July 2100 UTC, 16 July 0000UTC to 0900 UTC 200-850 hPa wind shear on 16 July 2004 are shown in Figure C1a and C2a to C2d (in central colour plate), this period spanning the time from when Kompasu just began interacting with land to about one and half hours after landfall. There no significant shear observed at 2100 UTC on 15 July (Figure C1a). 3 hours later, at 0000 UTC on 16 July, the 200-850 hPa shear was about 2.5 m/s from the northwest, and increasing further to about 12 m/s from the north-northeast 9 hours later. Between 0000 UTC and 0900 UTC on 16 July, the convection was found to be downstream of the shear vector (Figure C2a to C2d). This result is consistent with that found by Chan et al. (2004) for Typhoon Sam which made landfall over Hong Kong in August 1999.

#### 4. Conclusions

Following landfall, Tropical Storm Kompasu's low level centre showed a vertical tilt to the west. The distribution of convection around its centre also became asymmetrical. This asymmetry was related to the 200-850 hPa wind shear, with the main convection found downwind of the shear vector.

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## Weather and Japanese Encephalitis in Hong Kong

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#### 1. Introduction

Japanese Encephalitis (JE) is one of the most serious vector-borne diseases in Asia. Countries in tropical, sub-tropical and temperate zones such as China, Indonesia, Japan, Malaysia, Thailand, Vietnam, etc, have been affected (Peng et al 2003). The JE virus is transmitted by the bite of infected rice field breeding mosquitoes, principally *Culex tritaeniorhynchus* (CHP 2004). These mosquitoes became infective after feeding on JE infected pigs or wild birds, the principal amplifying hosts. Although humans can be infected, they are dead end hosts and JE virus is not transmitted from person to person. In Hong Kong, JE is not a common disease with an average of about one case per year, mostly occurring in the New Territories. There was only one JE case in Hong Kong in the 1990s. However, after nearly a decade of inactivity, the five local JE cases reported in 2004 revived the public's concern towards this risk to public health.

Studies of JE in other Asian countries suggested that weather is one of the key factors affecting the transmission of JE (WHO 2004, Suwannee et al 1997, Peng et al 2003). Using the data of local JE cases and the corresponding monthly meteorological observations, this study attempts to identify the seasonal variation of and favorable weather conditions for the occurrence of JE cases in Hong Kong.

Section 2 describes the data sources and analysis used in the study. Results of the analysis are presented in Section 3 and observations in Section 4.

## 2. Data and Analysis

- 2.1 The data of local JE cases from 1967 to 2004 were obtained from the Working Group on Japanese Encephalitis (WGJE) of the Department of Health, convened by the Scientific Committee on Advanced Data Analysis and Disease Modelling (SCADADM). In total 37 JE cases were reported in Hong Kong since 1967. However, information on the month of occurrence of five of the JE cases was missing, so only 32 JE cases were used in this study. Table 1 lists the district and day/month of the occurrence of the 32 JE cases.
- 2.2 The following meteorological elements from 1967 to 2004 were used in the study:
- (i) Monthly mean, mean maximum and mean minimum temperatures at the Hong Kong Observatory Headquarters;
- (ii) Monthly rainfall at the Hong Kong Observatory Headquarters:
- (iii) Monthly mean relative humidity at the Hong Kong Observatory Headquarters;
- (iv) Monthly bright sunshine hours at the King's Park Meteorological Station
- (v) Monthly mean wind speed at Waglan Island (1968-2004); and
- (vi) Climatological normals (1961-1990) of the elements (i) to (v).

Table 1. Brief Summary of Japanese Encephalitis cases in Hong Kong (1967-2004)

Year	Month	District
1967	July	Castle Peak
1967	August	Tai Wo Hau
1969	June	Lok Ma Chau
1971	August	Tai Po
1971	August	Yuen Long
1971	August	Yuen Long
1971	October	Sheung Shui
1972	March	Kwun Tong/Aberdeen
1972	August	Lantau Island
1973	September	Tai Po
1973	December	Sai Kung
1975	June	Shatin
1976	November	Yuen Long
1977	May	Cheung Sha Wan
1977	July	Tai Wai
1977	August	Kam Tin
1977	August	Shek Kong
1979	June	rural
1979	July	Rural
1981	December	Yuen Long
1982	June	Tai Koo Shing
1982	October	Tsuen Wan
1988	June	Yuen Long
1988	November	
1989	19 June	Fanling
1996	1 July	Fanling
2003	25 October	Yuen Long, Fairview
2004	29 May	Kwai Chung
2004	8 June	Yuen Long
2004	11 June	Sham Shui Po
2004	16 October	Yuen Long
2004	1 November	Southern (Hong Kong Island)

2.3 The monthly mean values of the above meteorological elements for the months and years with the occurrence of JE cases were extracted for the study. As the number of JE cases between 1967 and 2004 was scarce (on average about 1 case per year) and spread out throughout the year, the data were analyzed on a seasonal rather than monthly basis to increase the sample size. In this study, the definition of the four seasons in Hong Kong that was used in a previous climate change study was adopted (Leung et al 2004). Spring refers to March to May, summer from June to August, autumn from September to November and winter from December to February. The frequency distributions of the JE cases for different meteorological elements were also studied.

2.4 To cater for the variation of the monthly mean values within a season, the number of JE cases versus the anomalies of the monthly mean value of each meteorological element mentioned in Section 2.2 was examined. The anomaly of the monthly mean is defined as:

anomaly = monthly mean of the month - climatological monthly mean

Taking the mean temperature of a particular month as an example, positive (negative) anomaly indicates the month is warmer (colder) than the climatological normal. The 1961-1990 climatological normals for different meteorological elements are given in Appendix 1.

2.5 The scattered plot method (Stanski et al 1989) which displays the distribution of JE cases between two meteorological elements was also used to investigate the tendency of occurrence of JE cases in different weather scenarios.

#### 3. Results

#### 3.1 Seasonal Variation

Figure 1 shows the frequency distribution of JE cases in different months and seasons. It revealed that JE occurred more often in summer (June to August) and there was a secondary peak in October, the middle of autumn. JE cases occurred less frequently in winter and spring. Furthermore, no JE case had been reported in January and February since 1967.

## 3.2 <u>Effect of Meteorological Elements</u>

#### 3.2.1 Air Temperature

Figures 2(a), 2(b) and 2(c) show respectively the frequency distribution of monthly mean temperature, monthly mean minimum temperature and monthly mean maximum temperature for the JE cases. Figure 2(a) indicates that local JE cases occurred commonly in months with mean temperature of around 28 to 29 degrees Celsius and became less frequent when the monthly mean temperature was lower than 19 degrees Celsius or over 29 degrees Celsius. Similarly, as shown in Figure 2(b), local JE cases occurred mainly in months with the mean minimum temperatures ranging from 26 to 27 degrees Celsius. However, a wider spread (28 to 33 degrees Celsius) is observed in the monthly mean maximum temperature distribution (Figure 2(c)).

Appendix 1. Climatological Normals of Hong Kong 1961-1990.

	Ai	r Temperatı	ire	Mean	Total	Total	Mean
Month	Mean	Maan	Mean	Relative	Bright	Total Rainfall	Wind
Month	Daily Max.	Mean	Daily Min.	Humidity	Sunshine	Kallilali	Speed
	deg C	deg C	deg C	%	hours	mm	m/s
January	18.6	15.8	13.6	71	152.4	23.4	6.7
February	18.6	15.9	13.9	78	97.7	48	7.1
March	21.3	18.5	16.5	81	96.4	66.9	6.1
April	24.9	22.2	20.2	83	108.9	161.5	5.5
May	28.7	25.9	23.9	83	153.8	316.7	5.3
June	30.3	27.8	25.9	82	161.1	376	6
July	31.5	28.8	26.6	80	231.1	323.5	5.6
August	31.3	28.4	26.3	81	207	391.4	5.1
September	30.3	27.6	25.5	78	181.7	299.7	6.1
October	27.9	25.2	23.1	73	195	144.8	7.7
November	24.2	21.4	19.2	69	181.5	35.1	7.6
December	20.5	17.6	15.4	68	181.5	27.3	7.1

Hong Kong Observatory Headquarters : Air Temperatures, Mean Relative Humidity and Total Rainfall

King's Park: Total Bright Sunshine Waglan Island: Mean Wind Speed

Figure 1. Monthly Distribution of Japanese Encephalitis (JE) cases in Hong Kong from 1967 to 2004.

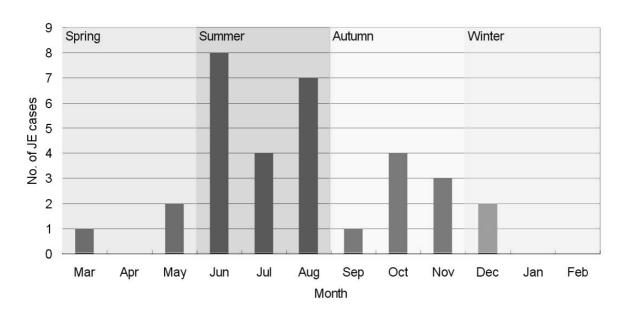


Figure 2(a). Frequency Distribution of Monthly Mean Temperature for JE cases from 1967 to 2004.

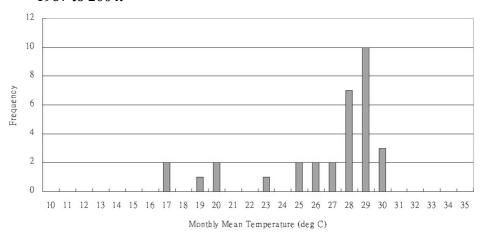


Figure 2(b). Frequency Distribution of Monthly Minimum Temperature for JE cases from 1967 to 2004.

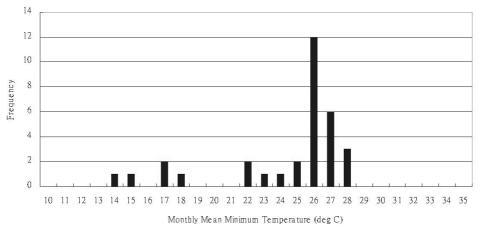
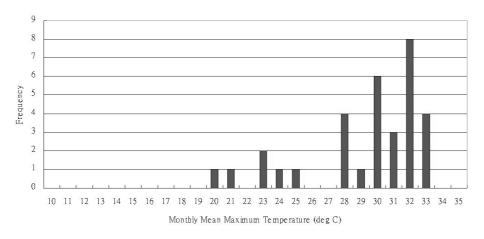


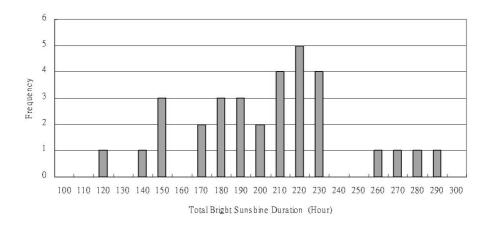
Figure 2(c). Frequency Distribution of Monthly Mean Maximum Temperature for JE cases from 1967 to 2004.



#### 3.2.2 Bright Sunshine Duration

The frequency distribution of monthly total bright sunshine for local JE cases is presented in Figure 3. Most JE cases occurred in months with total bright sunshine of 150 to 230 hours. There appears to be a threshold of 110 hours below which JE cases have not occurred since 1967.

Figure 3. Frequency Distribution of Monthly Total Sunshine Duration for JE cases from 1967 to 2004.



## 3.2.3 Other Meteorological Elements

Figure 4 indicates that local JE cases could occur in both dry and rainy months. Figures 5 and 6 also suggest that JE cases could occur over a wide range of monthly mean relative humidity and monthly mean wind speed values.

Figure 4. Frequency Distribution of Monthly Total Rainfall for JE cases from 1967 to 2004.

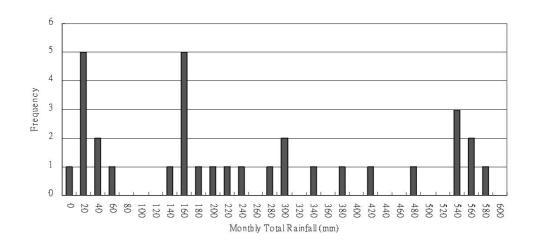


Figure 5. Frequency Distribution of Monthly Mean Relative Humidity for JE cases from 1967 to 2004.

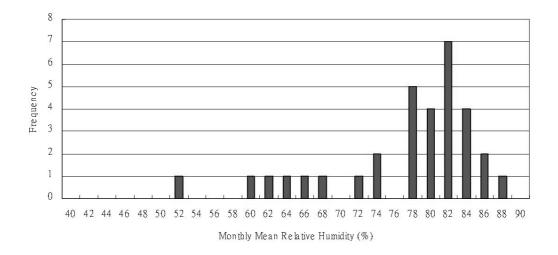
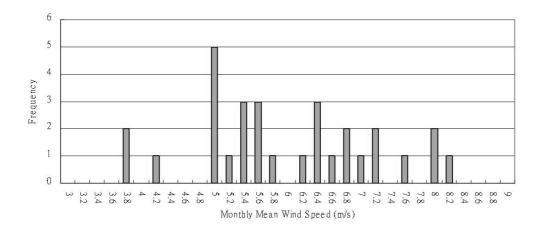


Figure 6. Frequency Distribution of Monthly Mean Wind Speed (Waglan Island) for JE cases from 1967 to 2004.



## 3.3 <u>Anomaly Analysis</u>

#### 3.3.1 JE Cases in Summer

Table 2 shows the anomalies of different meteorological elements for the JE cases in summer. Apart from the monthly mean wind speed which has a negative bias (12 out of the 17 JE cases occurred in below normal wind speed scenario), there is no significant bias on the occurrence of JE for most of the meteorological elements.

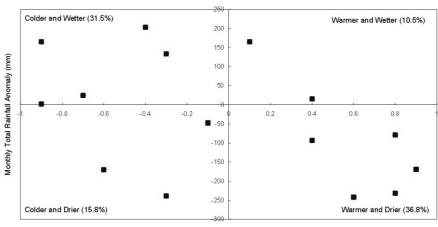
The scatter plot between monthly mean temperature anomaly and monthly total rainfall anomaly (Figure 7(a)) for JE cases also shows a distribution pattern similar to that for all months in summer (June – August) in 1967-2004 (Figure 7(b)). This reflects that, in summer, the occurrence of JE cases has no noticeable tendency on a particular weather situation. Similar results were also obtained for other combinations of meteorological elements (diagrams not shown here).

Table 2. Summary of anomalies of the monthly meteorological observations for Japanese Encephalitis in Hong Kong from June to August (1967 to 2004)

	Air	r Temperat	ure	Mean	Total	Total	Mean
Month / Year	Mean Daily Max.	Mean	Mean Daily Min.	Relative Humidity	Bright Sunshine	Rainfall	Wind Speed
	deg C	deg C	deg C	%	hours	mm	m/s
July 1967	1.1	0.9	0.7	-3	52.6	-169.4	-
July 1977	0	-0.1	0.2	4	-41.6	-47.4	-0.3
July 1979	0.6	0.4	0.6	-1	42.6	15.9	-0.7
July 1996	0.3	0.4	0.5	-1	-14.7	-93.2	1
June 1969	-0.4	-0.7	-0.6	2	-12.2	24.7	-0.7
June 1975	-0.5	-0.4	-0.4	3	-49.8	203.6	-0.2
June 1979	-0.6	-0.9	-0.8	3	-19	2.2	-0.8
June 1982	-1.1	-0.6	-0.4	-1	-30	-170.1	1.9
June 1988	1	0.8	0.8	-4	48.6	-79.1	-0.5
June 1989	-0.6	-0.3	0.1	1	18.1	-238.5	0.8
June 2004	0.5	0.8	0.9	-4	44.2	-231.3	-0.5
June 2004	0.5	0.8	0.9	-4	44.2	-231.3	-0.5
August 1967	-0.1	0.1	-0.3	1.0	-29.7	165.3	-
August 1971	-0.1	-0.3	-0.6	0.0	17.4	134.1	-0.2
August 1971	-0.1	-0.3	-0.6	0.0	17.4	134.1	-0.2
August 1971	-0.1	-0.3	-0.6	0.0	17.4	134.1	-0.2
August 1972	-0.9	-0.9	-0.7	6.0	-30.8	165.4	0.3
August 1977	0.8	0.6	0.5	-1.0	12.1	-241.7	-1.3
August 1977	0.8	0.6	0.5	-1.0	12.1	-241.7	-1.3
Mean Bias	0.06	0.03	0.04	0.00	5.21	-40.23	-0.20
No. of +ve bias cases	10	10	10	9	11	10	4
No. of -ve bias cases	9	9	9	10	8	9	13

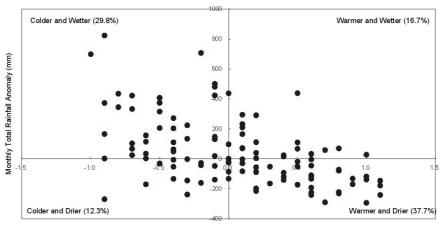
negative bias cases positive bias cases

Figure 7(a). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Rainfall Anomaly for JE cases in Summer (June to August).



Monthly Mean Temperature Anomaly (deg C)

Figure 7(b). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Rainfall Anomaly from June to August in 1967 to 2004.



Monthly Mean Temperature Anomaly (deg C)

#### 3.3.2 JE Cases in Autumn and Winter

As there are only two JE cases in winter and both occurred in December, to increase the sample size, the JE cases from September to December was grouped together in this part of the study (total 10 cases). Table 3 shows the anomalies of different meteorological elements for the JE cases from September to December. In contrast to the summer scenario, the JE cases from September to December have noticeable negative bias in the temperatures, relative humidity and total rainfall and positive bias in total bright sunshine duration.

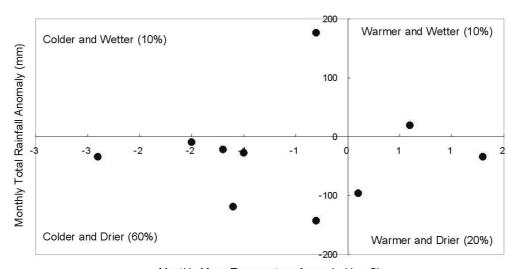
Figures 8(a), 9(a) and 10(a) show the scatter plot between monthly mean temperature anomaly, monthly total rainfall anomaly and monthly total bright sunshine anomaly for JE cases from September to December respectively. When compared with the corresponding scatter plots for all the Septembers, Octobers, Novembers and Decembers from 1967 to 2004 (Figures 8(b), 9(b) and 10(b)), JE cases appear to occur more often in colder, drier and sunnier situation.

Table 3. Summary of anomalies of the monthly meteorological observations for Japanese Encephalitis in Hong Kong from September to December (1967 to 2004).

Month / Year	Ai Mean Daily Max.	r Temperatu Mean	nre Mean Daily Min.	Mean Relative Humidity	Total Bright Sunshine	Total Rainfall	Mean Wind Speed
	deg C	deg C	deg C	%	hours	mm	m/s
October 1971	-0.5	-1.1	-1.3	-6.0	1.8	-118.8	0.3
October 1982	-0.1	0.6	1.0	4.0	-27.7	18.9	-0.6
October 2003	-0.8	0.1	0.5	-2.0	28.7	-96.2	-1.5
October 2004	-0.4	-0.3	-0.2	-9.0	62.4	-142.5	-1.4
November 1976	-2.0	-2.4	-2.6	-7.0	21.6	-34.3	0.6
November 1988	-1.8	-1.5	-1.6	-3.0	16.9	-9.5	-0.6
November 2004	0.3	1.3	1.9	4.0	2.4	-34.7	-0.8
September 1973	-0.3	-0.3	-0.2	6.0	-39.5	176.3	1.1
December 1973	0.3	-1.0	-1.7	-17.0	86.9	-27.3	0.5
December 1981	-1.4	-1.2	-1.2	-8.0	33.2	-21.9	-0.8
Mean Bias	-0.7	-0.6	-0.5	-3.8	18.7	-29.0	-0.3
No. of +ve bias cases	2	3	3	3	8	2	4
No. of -ve bias cases	8	7	7	7	2	8	6

negative bias cases
positive bias cases

Figure 8(a). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Rainfall Anomaly for JE cases from September to December in 1967 to 2004.



Monthly Mean Temperature Anomaly (deg C)

Figure 8(b). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Rainfall Anomaly from September to December in 1967 to 2004.

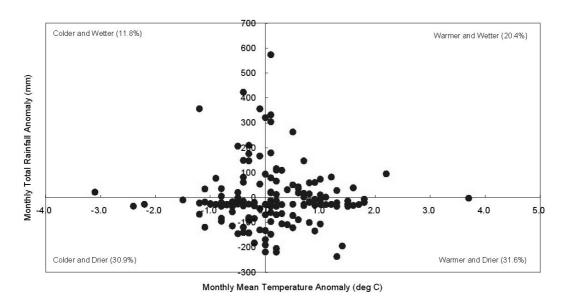


Figure 9(a). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Bright Sunshine Anomaly for JE cases from September to December in 1967 to 2004.

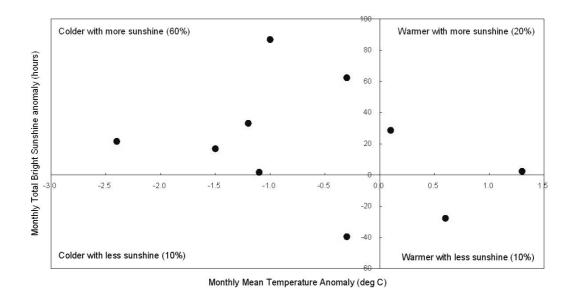


Figure 9(b). Scatter Plot between Monthly Mean Temperature Anomaly and Monthly Total Bright Sunshine Anomaly from September to December in 1967 to 2004.

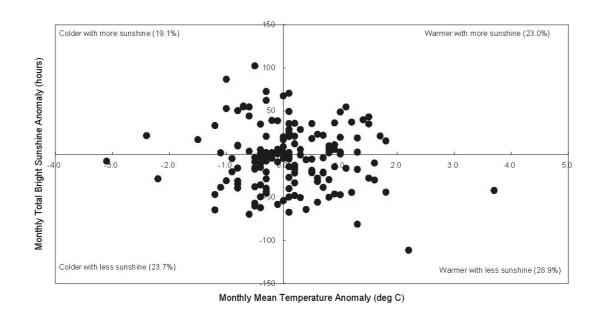


Figure 10(a). Scatter Plot between Monthly Total Rainfall Anomaly and Monthly Total Bright Sunshine Anomaly for JE cases from September to December in 1967 to 2004.

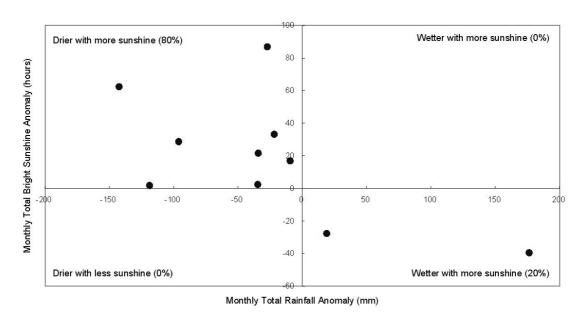
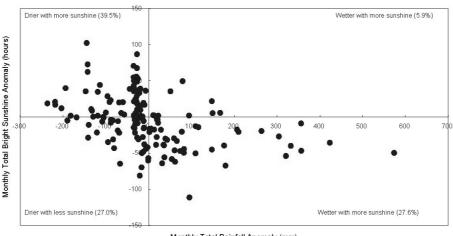


Figure 10(b). Scatter Plot between Monthly Total Rainfall Anomaly and Monthly Total Bright Sunshine Anomaly from September to December in 1967 to 2004.



#### Monthly Total Rainfall Anomaly (mm)

#### 4. Observations

- 4 1 The occurrence of JE cases in Hong Kong has a distinguishable seasonal variation with summer (June to August) being the high season. There is also another secondary peak of occurrence in October. Local JE cases seldom happen in winter and spring. In fact, no JE case had been reported in January and February since 1967. Such seasonal variation in local JE cases is likely to be due to the effect of air temperature on the abundance of mosquitoes. According to the studies of Mellor et al (Mellor et al 2000) and Reiter (Reiter 1988), a rise in air temperature will induce bloodfeeding of mosquitoes, consequently enhancing egg production and leading to an increase in population size. On the other hand, the daily survival rate of mosquitoes is likely to decrease when air temperature rises and there exists an upper limit beyond which high air temperature is detrimental. The frequency distribution analysis presented in Section 3.2 further reveals that, while JE cases in Hong Kong occurred most frequently in summer months with the mean temperature ranging from 28 to 29 degrees, the number of JE cases dropped quickly when the mean temperature fell below 19 degrees or exceeded 29 degrees. Besides dependence on air temperature, no JE case was found to occur in a month with total bright sunshine duration less than 110 hours.
- 4.2 The occurrence of local JE cases in summer has a neutral response to the variation in the anomaly of temperature, rainfall, sunshine and relative humidity. Slightly more JE cases occurred in less windy summer months. However, from September to December, local JE cases tends to occur more frequent in months which are colder, sunnier and drier than normal, despite the fact that the colder and sunnier situation is not predominant in such a period. Other than the JE vector, the behavior of human and other hosts is also an influential factor to JE transmission (Reiter 1988). In Hong Kong, outdoor activities in autumn and winter, such as hiking, picnic and camping, are greatly affected by weather. Usually, sunnier, drier and colder months attract more people to country parks and rural areas where mosquitoes are common. This may consequently increase the chance of JE infection.

4.3 We caution that our analysis is limited by the small number of reported JE cases and consequently suffers from reduced statistical power which may in turn lead to spurious conclusions. Moreover, this type of correlational analysis poses a known pitfall called "ecologic fallacy" where macro-level associations may not hold on closer examination in individual cases. Nevertheless, these findings provide unique new insights and testable hypotheses to guide future work and are useful in monitoring secular changes in meteorological factors as they relate to the occurrence of JE cases in Hong Kong.

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