Development of an Operational Storm Surge Prediction System for a Coastal City – Hong Kong Experience

Part 1 – Impact of historical storm surge in Hong Kong

Typhoon Committee Roving Seminar 2016

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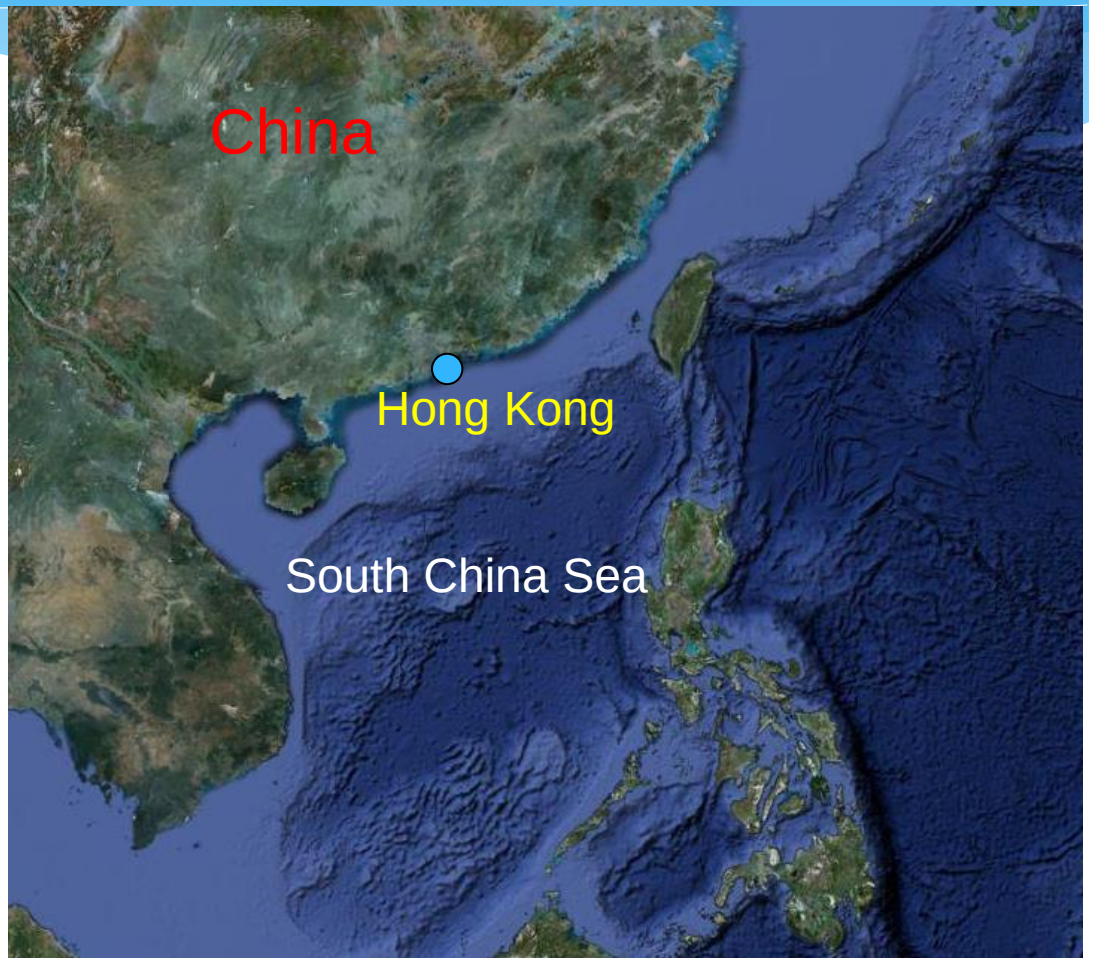
* Hong Kong is situated on the coast of southern China facing South China Sea
* On average, about 6-7 tropical cyclones affect Hong Kong each year
* Vulnerable to sea flooding due to storm surge caused by approaching tropical cyclones
* Historically, the storm surge in 1906 and 1937 brought great causalities



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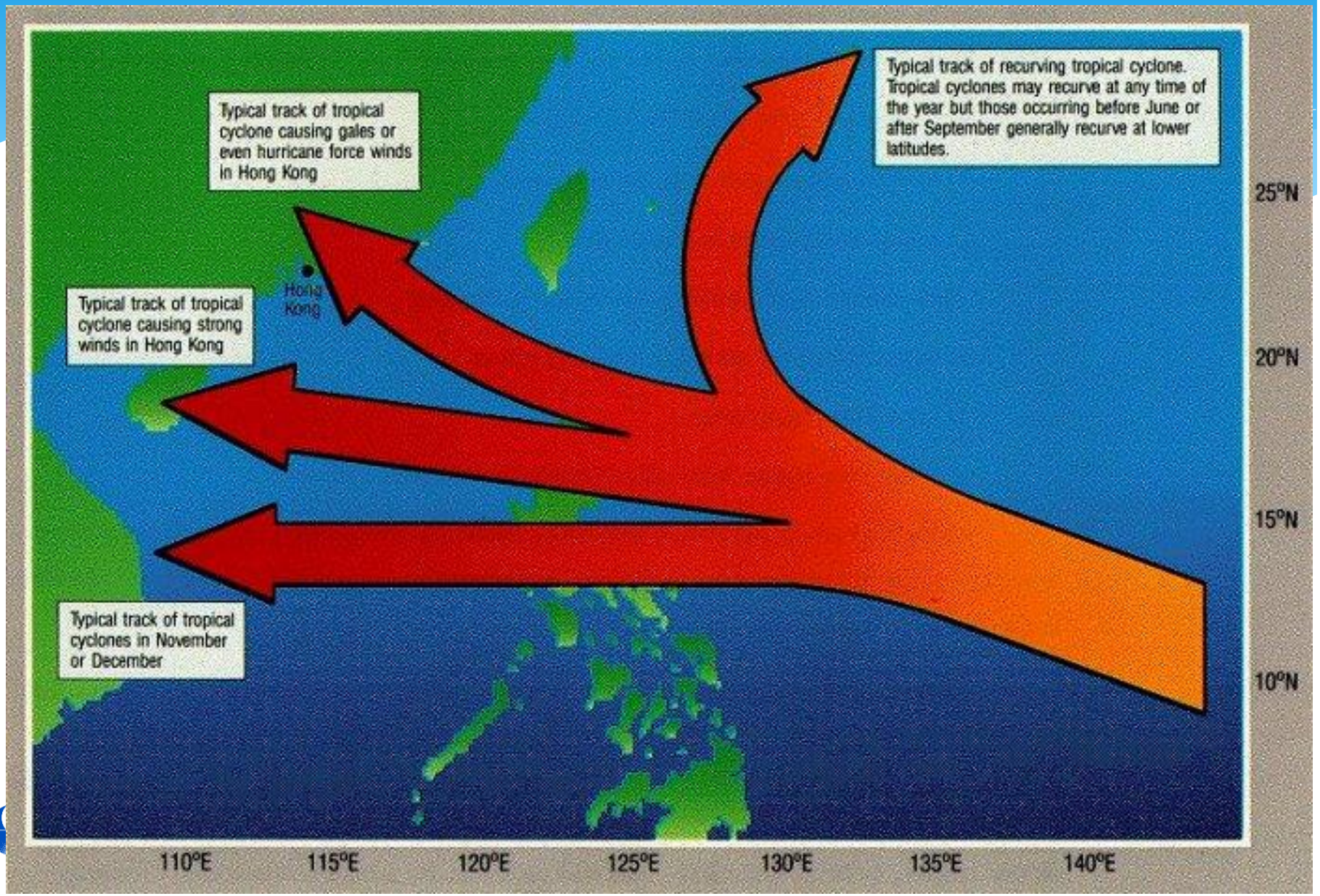
Typical track of tropical cyclone from the Pacific Ocean



Tropical Cyclone warning

Meaning of signals

1 A tropical cyclone is centred within about 800 kilometres (km) of Hong Kong and may affect the territory.

3 Strong wind is expected or blowing generally in Hong Kong near sea level, with a sustained speed of 41-62 kilometres per hour (km/h), and gusts which may exceed 110 km/h, and the wind condition is expected to persist.

8 Gale or storm force wind is expected or blowing generally in Hong Kong near sea level, with a sustained wind speed of 63-117 km/h from the quarter indicated and gusts which may exceed 180 km/h, and the wind condition is expected to persist.

9 Gale or storm force wind is increasing or expected to increase significantly in strength.

10 Hurricane force wind is expected or blowing with sustained speed reaching upwards from 118 km/h and gusts that may exceed 220 km/h.

Important points to note

- The weather in different parts of Hong Kong cannot be simply inferred from the signal issued. Simply knowing what signal is issued is not enough. **You should** take note of the latest tropical cyclone information and related announcements broadcast on radio and TV, and given in the Hong Kong Observatory's Internet website (http://www.hko.gov.hk and http://www.weather.gov.hk) and Dial-a-Weather system (Tel. No.: 1878 200) to decide on the actions to take in response to the signal issued.
- Tropical cyclone warning signals are to warn the public of the threat of **WINDS** associated with a tropical cyclone.
- Owing to local topographical conditions or the presence of buildings nearby, winds at your locality may be substantially different from the general wind strength over Hong Kong. Winds are often stronger over offshore waters and on high ground. Winds are less strong in areas sheltered from the prevailing wind direction.
- The Hong Kong Observatory provides to the public detailed information on regional wind and rain through a diversity of channels, especially the Internet. Members of the public should consider their own circumstances and level of acceptable risk when taking precautions in response to warnings.
- When the No.1 signal is issued, you should take the existence of the tropical cyclone into account in planning your activities and beware that strong winds may occur over offshore waters.
- When the No.3 signal is issued, secure all loose objects, particularly on balconies and roof tops. Secure hoardings, scaffoldings and temporary structures. Winds are normally expected to become generally strong in Hong Kong within 12 hours after this signal is issued. Winds over offshore waters and on high ground may reach gale force.
- When the No.8 signal is issued, complete all precautions before gales commence. Winds are normally expected to reach gale force generally in Hong Kong within 12 hours after No.8 signal replaces No.3 signal.
- When the No.9 or No.10 signal is issued, all precautions should be completed. Stay indoors and away from exposed windows and doors to avoid flying debris.

信號的意義

1 有一熱帶氣旋集結於香港約800公里的範圍內，可能影響本港。

3 香港近海平面處現正或預料會普遍吹強風，持續風力達每小時41至62公里，陣風更可能超過每小時110公里，且風勢可能持續。

8 香港近海平面處現正或預料會普遍受烈風或暴風從信號所示方向吹襲，持續風力達每小時63至117公里，陣風更可能超過每小時180公里，且風勢可能持續。

9 烈風或暴風的風力現正或預料會顯著加強。

10 風力現正或預料會達到颶風程度，持續風力達每小時118公里或以上，陣風更可能超過每小時220公里。

注意事項

- 香港不同地區的天氣情況不能夠單憑發出的信號推斷。只知道發出了什麼信號並不足夠，你應該留意電台、電視台及天文台網頁（網址為 http://www.hko.gov.hk 和 http://www.weather.gov.hk）及「打電話問天氣」系統（電話號碼：1878 200）所提供的熱帶氣旋最新消息及有關報告，然後就發出的信號決定採取適當的相應行動。
- 發出熱帶氣旋警告信號，是為了警告市民熱帶氣旋帶來的**風力**威脅。
- 受地形或鄰近建築物影響，你所在區域的風力與香港普遍風勢可能有顯著差異。離岸海域及高地風力通常較強，不當風的地區風力較弱。
- 天文台透過多種途徑，特別是互聯網，向公眾提供各區風力及雨量的詳細資料。市民應該因應各自的具體情況和可接受的風險水平，就警告採取適當的預防措施。
- 1號信號發出後，計劃活動時，要考慮熱帶氣旋的影響，並注意離岸海域可能有強風。
- 3號信號發出後，應把所有容易被風吹動的物件綁緊，置於露台及屋頂的物件更要綁緊；圍板、鷹架和臨時建築物亦應鞏固。發出3號信號後，通常在12小時之內香港會普遍吹強風，在離岸海域及高地的風力更可能達烈風程度。
- 8號信號發出後，應在烈風吹襲前完成所有預防措施。8號信號取代3號信號後，通常在12小時之內香港普遍風力會達烈風程度。
- 發出9號或10號信號時，市民應已採取所有預防措施。這時切勿外出，並應遠離當風的門窗，以免被隨風吹來的碎片擊中。

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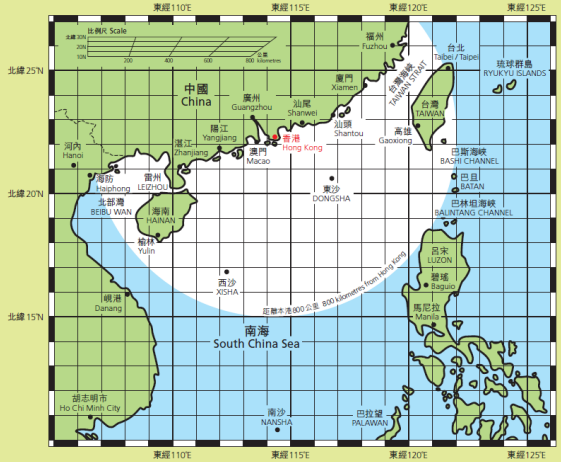
香港熱帶氣旋警告信號
Hong Kong's Tropical Cyclone Warning Signals

1	T	戒備 Standby
3	⊥	強風 Strong Wind
8 西北 NW	▲	西北烈風或暴風 NW'LY Gale or Storm
8 西南 SW	▼	西南烈風或暴風 SW'LY Gale or Storm
8 東北 NE	▲▲	東北烈風或暴風 NE'LY Gale or Storm
8 東南 SE	▼▼	東南烈風或暴風 SE'LY Gale or Storm
9	⧗	烈風或暴風風力增強 Increasing Gale or Storm
10	✚	颶風 Hurricane

香港
三沙預報警告

熱帶氣旋途徑繪畫圖
Tropical Cyclone Plotting Map



Designed by the Information Services Department
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Hong Kong Special Administrative Region Government

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June 2012

熱帶氣旋按下表分類
Tropical cyclones are classified as follows

	中心附近之最高持續風速（公里/小時） Maximum sustained winds near the centre (km/h)
熱帶低氣壓 Tropical Depression	62 或以下 or below
熱帶風暴 Tropical Storm	63 - 87
強烈熱帶風暴 Severe Tropical Storm	88 - 117
颱風 Typhoon	118 - 149
強颱風 Severe Typhoon	150 - 184
超強颱風 Super Typhoon	185 或以上 or more

在繪畫熱帶氣旋中心的移動途徑時，應留意偶然會出現偏離了一般動向的短期不規則性移動。出現這類偏差的原因部份由於確定熱帶氣旋中心位置的困難，而部份亦由於中心移動的方向及速度有短期性波動。

熱帶氣旋移動方向及距離香港的方位均以十六點方位表示，因此報告中的方位與實際方位可能相差達11¼度。例如，一颱風中心位於香港79至101度的任何方位，向259至281度任何方向移動，均可稱為"集結在香港以東…向西移動。"「區並非一定表示該颱風直擊香港，因其移動途徑與"直指香港"途徑之間可能相差逾22度。

When plotting the track of the centre of a tropical cyclone, it is important to note that there can be short term erratic departures from the general direction of movement. These departures are partly due to difficulties in locating the centre of the tropical cyclone, and partly due to short term fluctuations in the direction and speed of movement of the centre.

The direction towards which a tropical cyclone is moving and the bearing of its centre from Hong Kong are each given to the nearest point of a 16-point compass bearing. Thus the actual bearing will be within 11¼° of the reported value. For example, the centre of a typhoon on any bearing between 79° and 101° and moving on any heading between 259° and 281° is said to be "centred.....east of Hong Kong and moving west....." It will be seen that this statement does not necessarily mean that the centre is heading directly towards Hong Kong as its course could be as much as 22° off the direct "collision" course.

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Tropical cyclone warning bulletin

TROPICAL CYCLONE BULLETIN (SIGNAL NO. 8)[R]

[R]
HOURLY TC WARNING BULLETIN (URGENT)[R]

Tropical Cyclone Bulletin

Here is the latest Tropical Cyclone Bulletin issued by the Hong Kong Observatory.

The No. 8 Northeast Gale or Storm Signal is in force.

This means that winds with mean speeds of 63 kilometres per hour or more are expected from the northeast quarter.

At midnight, Typhoon Hagupit was centred about 200 kilometres south-southwest of Hong Kong (near 20.8 degrees north 113.1 degrees east) and is forecast to move west or west-northwest at about 28 kilometres per hour heading towards the western coast of Guangdong.

Hagupit is skirting past to the southwest of Hong Kong. It will remain at a distance of about 200 kilometres from Hong Kong in the next few hours. The No.8 Gale or Storm Signal will be in force throughout the overnight period.

Owing to the combined effect of Hagupit and high tide, tides at many places are currently running more than 1 metre above normal. The tide is higher than normal by about 1.6 metres at Tai Po Kau, and about 1.3 metres at Quarry Bay. Flooding is expected overnight in low lying areas.

In the past hour, the maximum sustained wind speeds recorded at Chek Lap Kok and Cheung Chau were 80 and 112 kilometres per hour respectively.

Storm Surge Report

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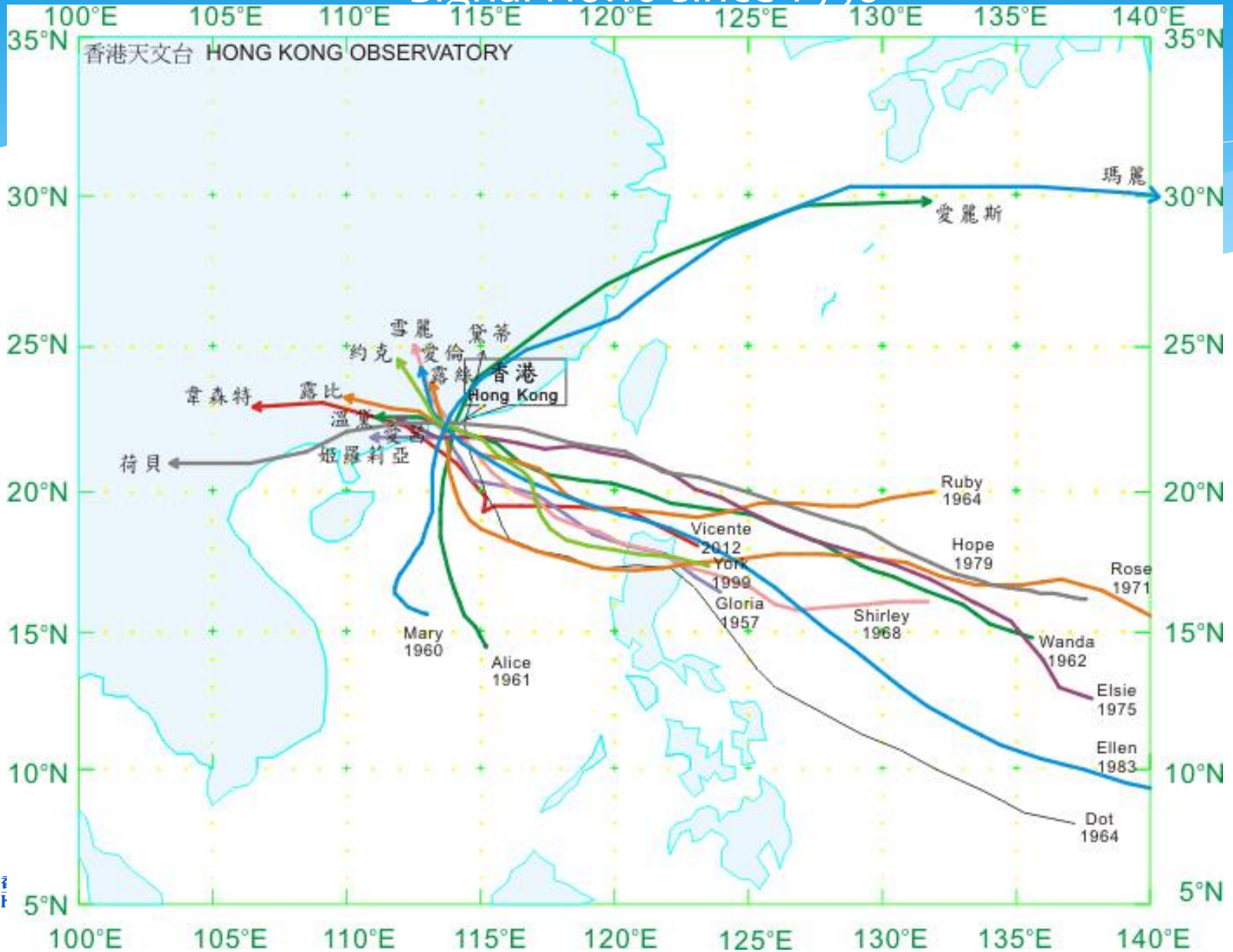
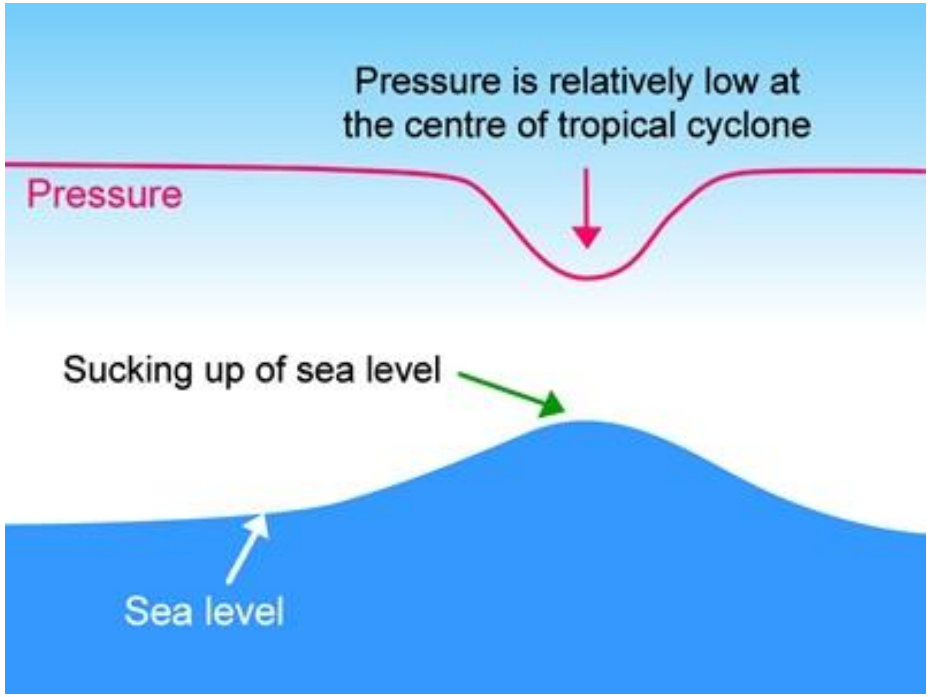
Tracks of typhoons requiring the issuing of the Hurricane Signal No.10 since 1956

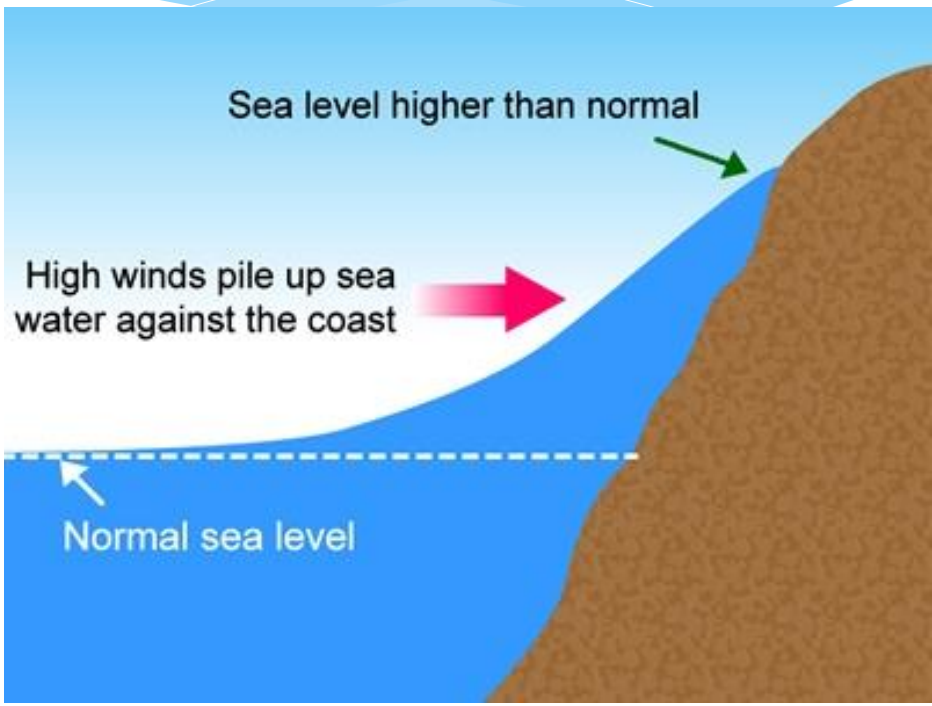


Storm Surge

Causes of storm surge by Tropical Cyclone



Low pressure



High winds

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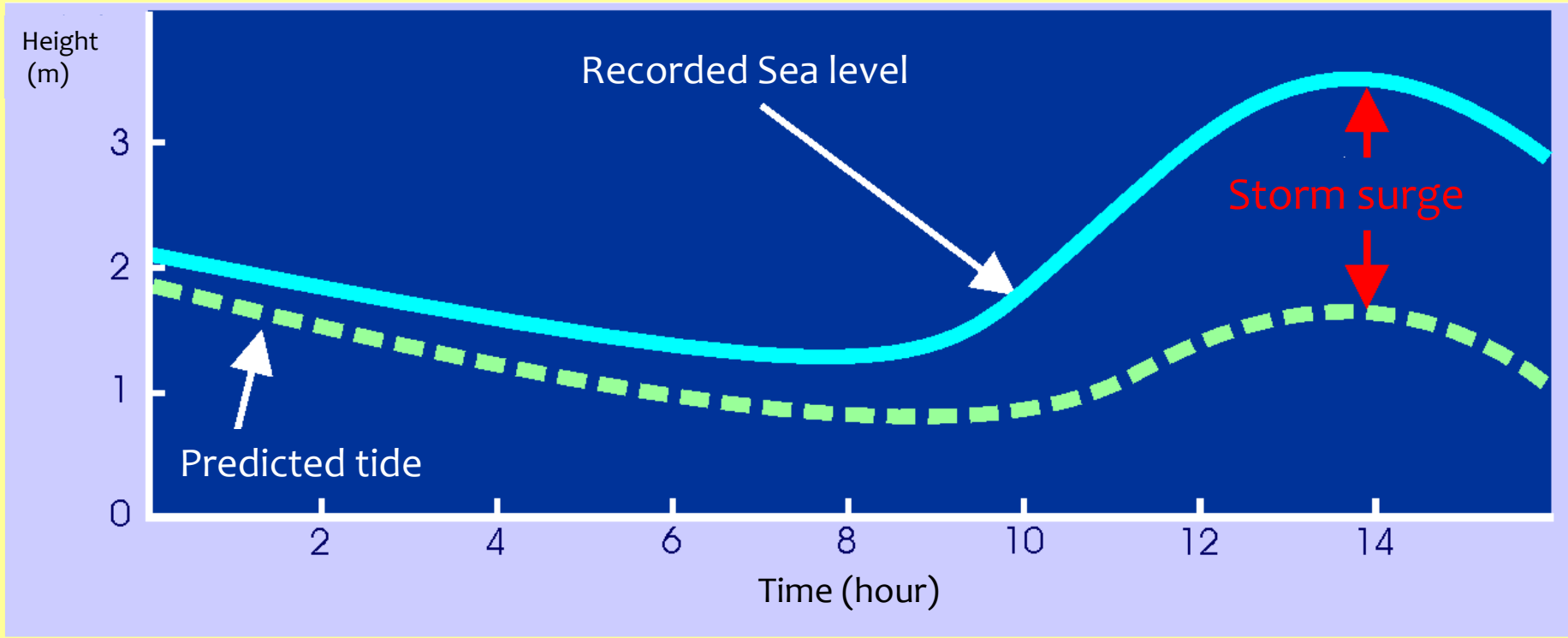
Storm surge

storm surge = recorded sea level – predicted astronomical tide



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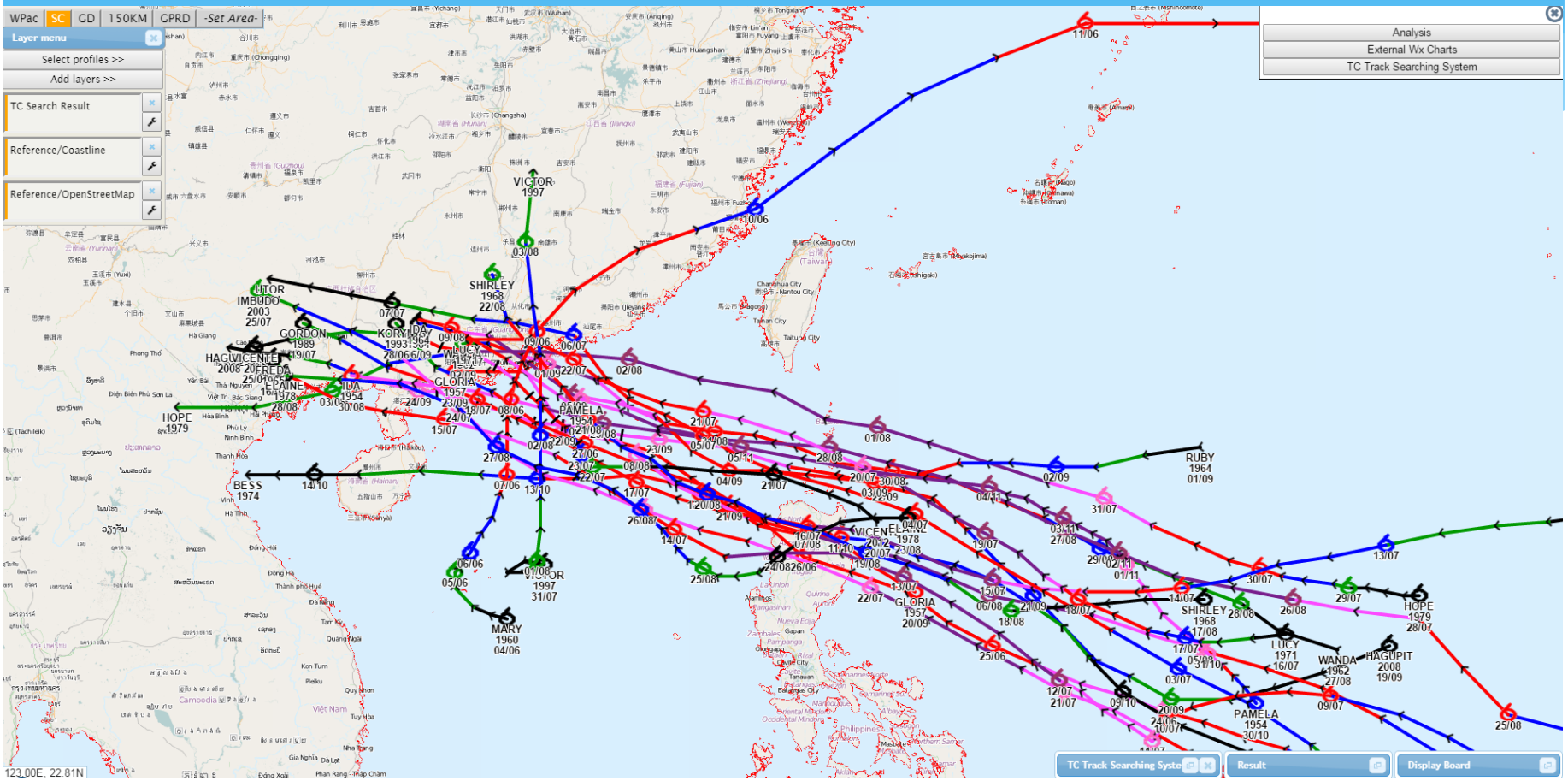
Tropical Cyclone Tracks For The Top 20 Storm Surge Records at Quarry Bay/North Point Tide Gauge Station (1954-2015)



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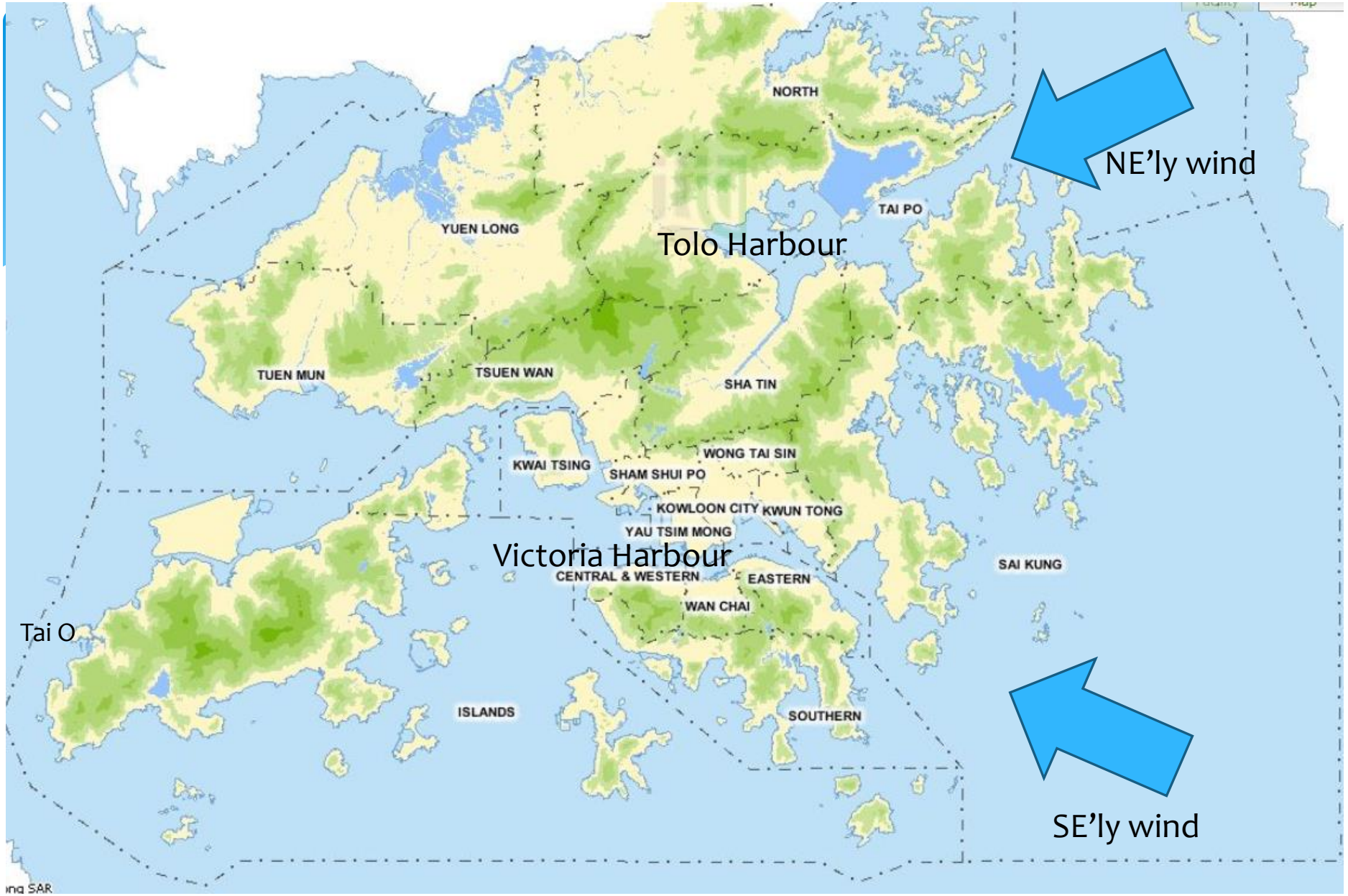

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Historical destructive Storm Surges in Hong Kong

Historical destructive Storm Surges in Hong Kong

Typhoon of 1906

* In the morning of 18 September 1906
* Suddenly arrived gales and storm surges of the typhoon
* Over 10,000 people were killed. It was a shockingly high figure for a small community of less than 450,000 people at that time.

A typhoon struck on 18 September 1906, causing the loss of more than 15,000 lives
(Courtesy Hong Kong Museum of History)

Connaught Road Central during the typhoon on 18 September 1906
(Courtesy Hong Kong SAR Public Records Office)

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Historical destructive Storm Surges in Hong Kong

Typhoon of 1937

* Villages along the coast of Tolo Harbour were severely flooded
* Thousands of lives were lost, mostly fishermen who were living in their boats.
* The high water mark in the area left by the typhoon was estimated to be about 6 metres, which meant a surge of about 3.8 metres
* Over 10,000 people were killed in each incident

The railway track at Sha Tim damaged by a typhoon in 1937. (Courtesy Hong Kong SAR Public Records Office)

Connaught Road Central during the typhoon on 18 September 1937. (Courtesy Hong Kong SAR Public Records Office)

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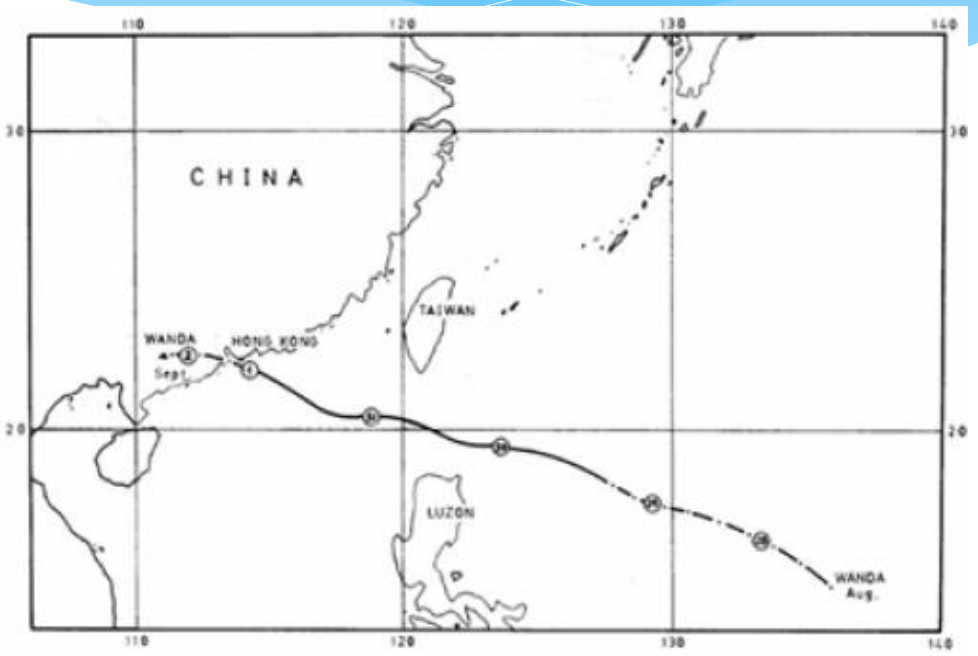
Historical destructive Storm Surges in Hong Kong

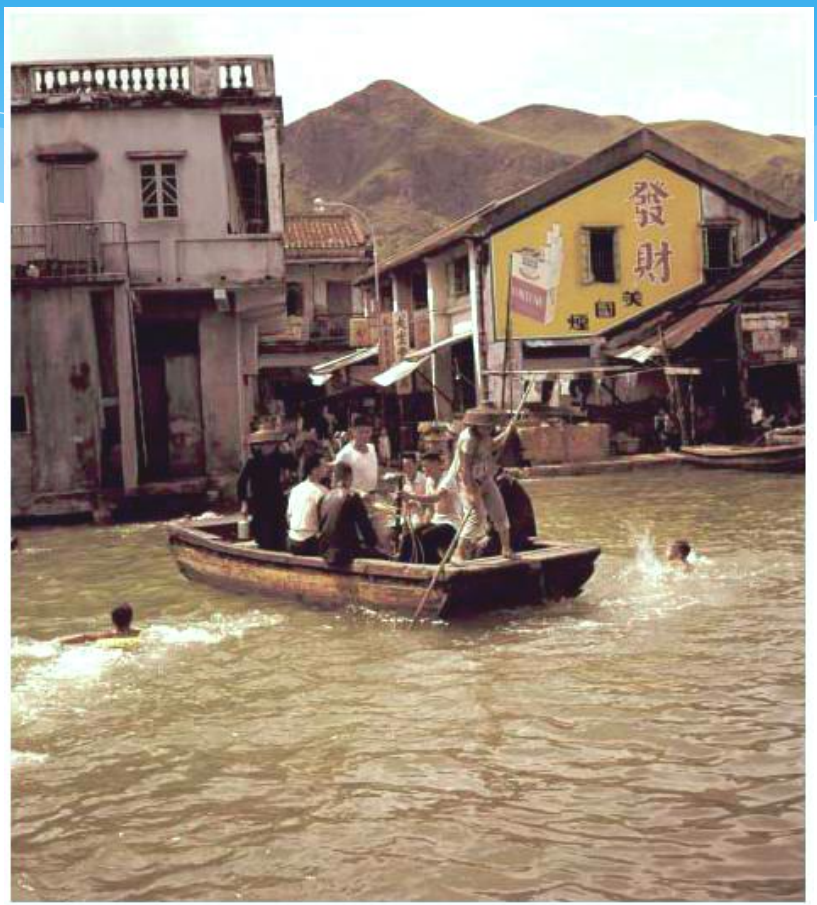
Super Typhoon Wanda (1962)

* Typhoon Wanda, which killed 183 people in 1962, claimed the third deadliest typhoon in Hong Kong since 1884
* Highest average wind speed : 234 km/h (max gusts : 259 km/h) recorded by HKO
* Lowest pressure recorded : 953.2 hPa
* In post- war years, the highest storm surge of 1.77m recorded at Victoria Harbour in September 1962
* Maximum sea level recorded was 3.96 metres

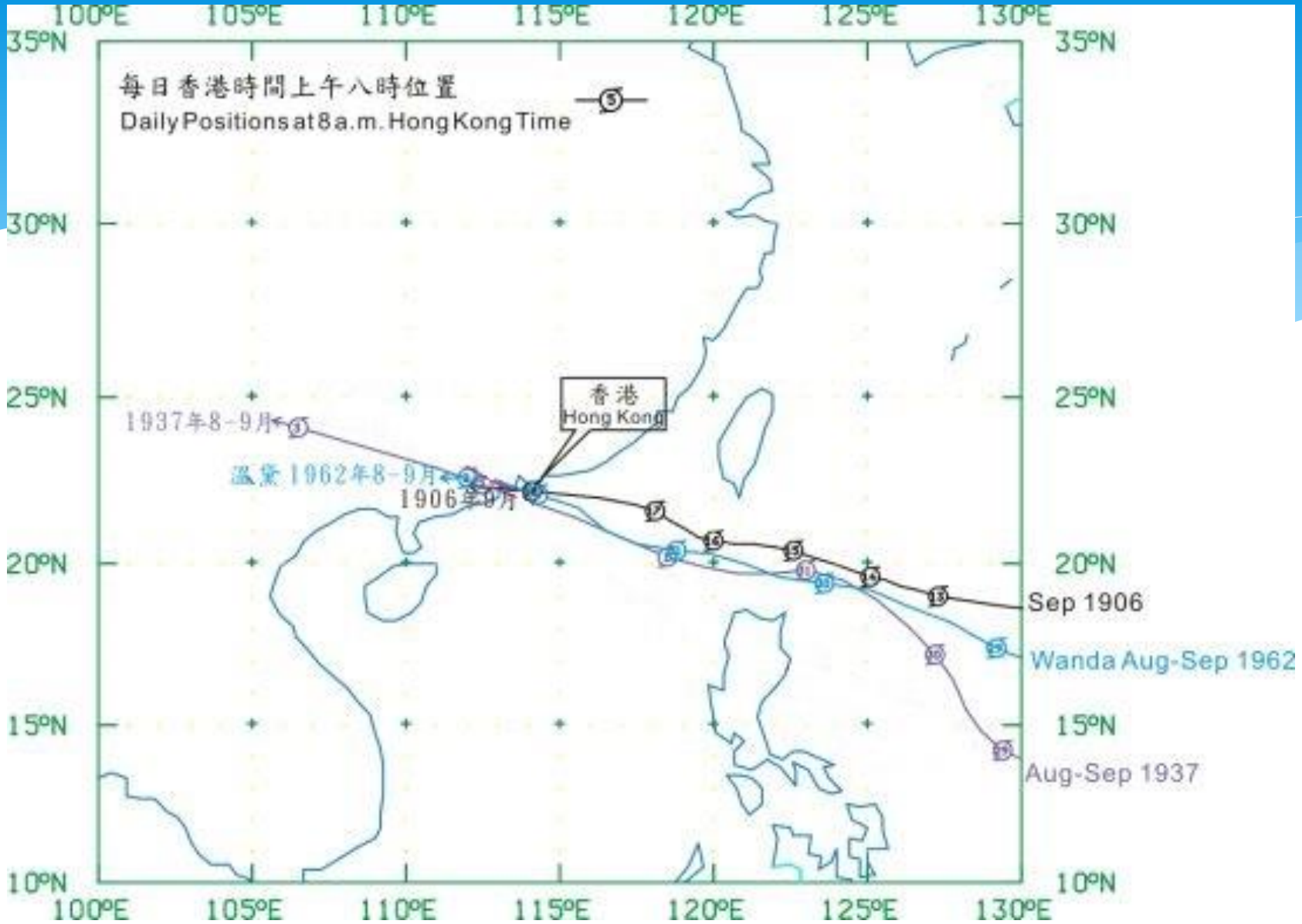


Damages caused by Wanda

Damaged by typhoon Wanda .
Courtesy Hong Kong SAR Information Services Department



Severe flooding at Sha Tin 1962
Courtesy Hong Kong SAR Information Services Department



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Historical destructive Storm Surges in Hong Kong

Super Typhoon Hope (1979)

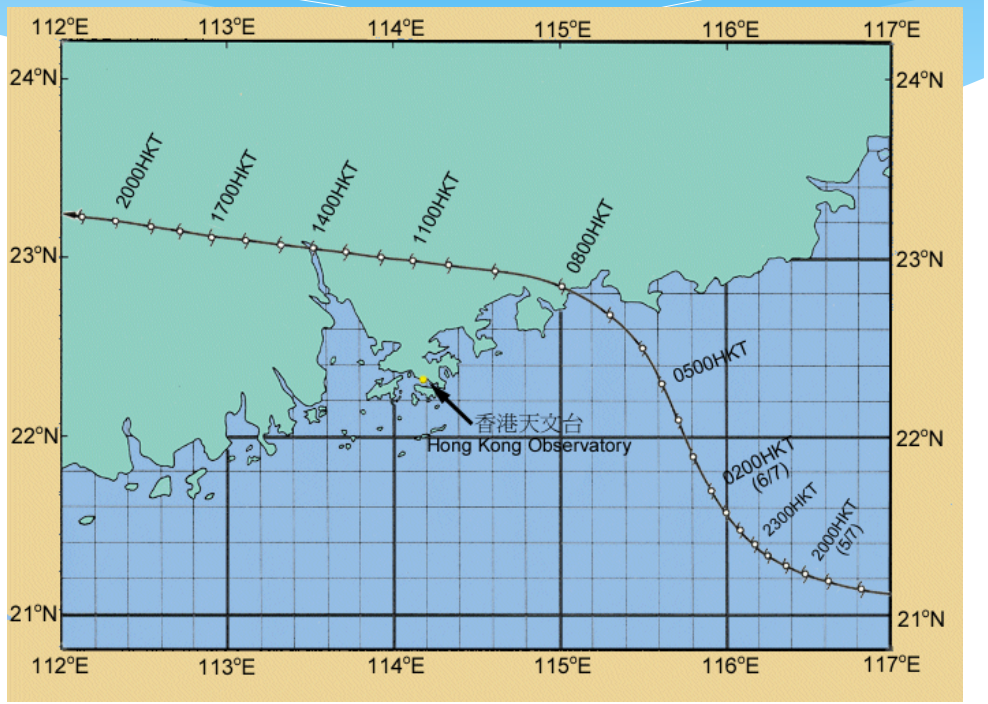
* The tide gauge at Tai Po Kau recorded a maximum surge of about 3.2 metres

Typhoon Utor (2001)

Significant storm surge in Hong Kong

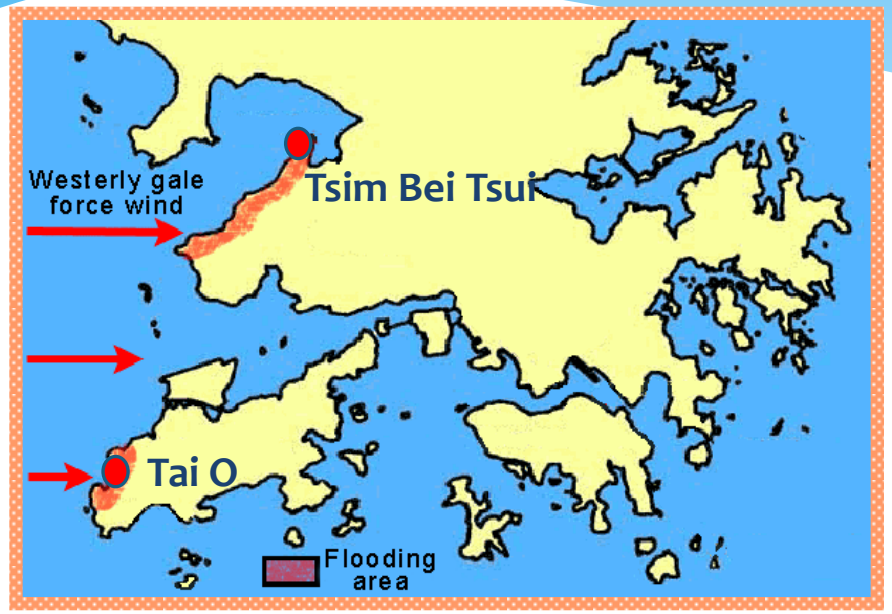
Both the tide gauges at Tsim Bei Tsui and Quarry Bay registered a maximum surge of about 1.1 metres.

Coupled with the astronomical high tide, sea levels reached 3.4 metres at Quarry Bay in that morning.



Track of Typhoon Utor in July 2001

Storm surge caused by Typhoon Utor in 2001

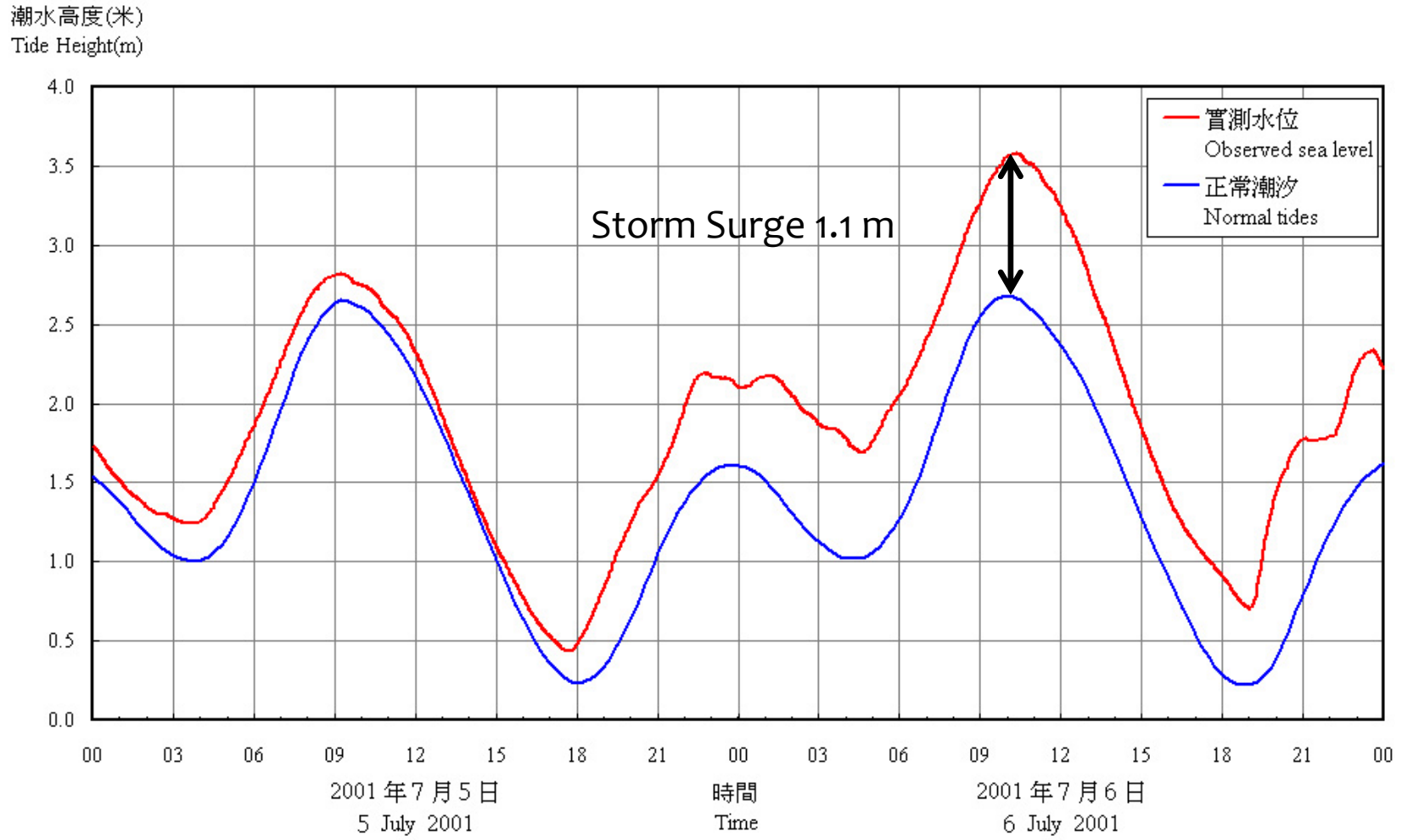


flooding to the northwestern part of the New Territories and Tai O of Lantau

（Courtesy Apple Daily）

Severe flooding in Tai O on 6 July 2001

Recorded sea level at Tsim Bei Tsui during the TC Utor in 2001



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年 Year	月 Month	熱帶氣旋名稱 Name of tropical cyclone	最高懸掛信號 Highest signal hoisted	最高水位 (米) Maximum sea-level (m)		最大風暴潮 (米) Maximum storm surge (m)	
				北角/鰂魚涌 North Point/ Quarry Bay	大埔滘 Tai Po Kau	北角/鰂魚涌 North Point/ Quarry Bay	大埔滘 Tai Po Kau
1962	9	Super Typhoon WANDA	10	3.96	5.03	1.77	3.20
1954	8	Super Typhoon IDA	9	3.18		1.68	
1964	9	Super Typhoon RUBY	10	3.14	3.54	1.49	2.96
1979	8	Super Typhoon HOPE	10	2.78	4.33	1.45	3.23
2008	9	Severe Typhoon HAGUPIT	8	3.53	3.77	1.43	1.77
1957	9	Severe Typhoon GLORIA	10	3.08		1.34	
1993	6	Severe Typhoon KORYN	8	2.61	3.01	1.34	1.46
1964	8	Super Typhoon IDA	9	2.86	3.63	1.31	2.16
1974	10	Typhoon BESS	3	3.13	3.22	1.23	1.13
1989	7	Super Typhoon GORDON	8	3.27	3.31	1.20	1.36
1954	7	Super PAMELA	9	2.83		1.16	
2001	7	Typhoon UTOR	8	3.38	3.47	1.12	1.35
2012	7	Severe VICENTE	10	2.76	3.09	1.11	1.47
1960	6	Typhoon MARY	10	2.77		1.10	
1968	8	Typhoon SHIRLEY	10	2.79	2.85	1.09	1.78
2003	7	Super Typhoon IMBUDO	8	2.75	2.66	1.02	1.05
1965	7	Super Typhoon FREDA	8	2.99	2.90	1.01	1.01
1997	8	Tyhoon VICTOR	9	2.76	2.73	1.01	0.70
1978	8	Severe Tropical Storm ELAINE	8	2.76	2.90	0.99	1.15
1971	7	Super Tyhoon LUCY	8	2.91	2.82	0.97	1.40

Maximum storm surge and sea level recorded in Hong Kong during the passage of tropical cyclones between 1954 and 2015

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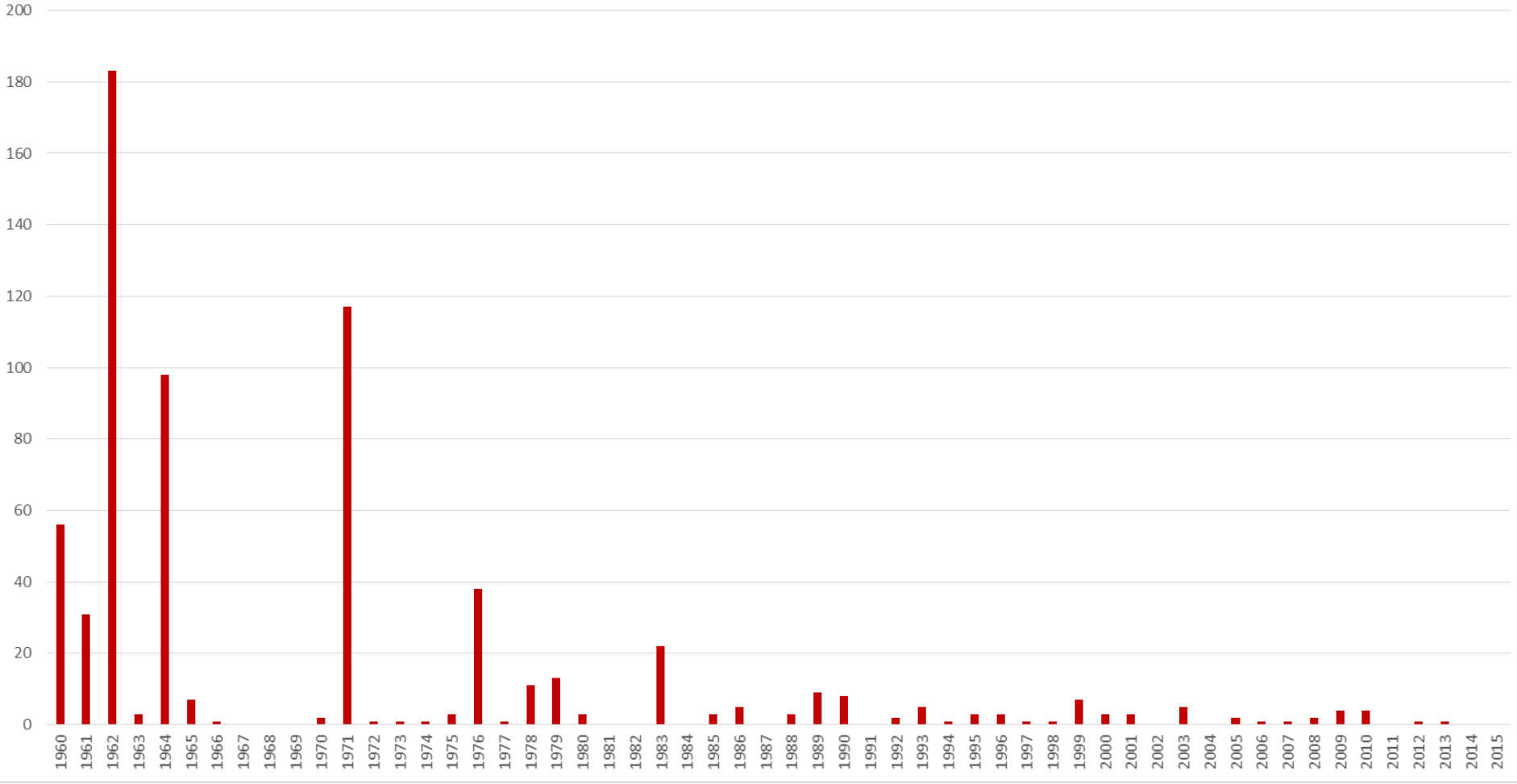
Typhoon name	Year	Maximum storm surge at Victoria Harbour (above astronomical tide) (m)	Maximum sea level at Victoria Harbour (above Chart Datum) (m)	Number of deaths
-	1906	1.83^	3.35^	~15,000*
-	1937	1.98^	4.05^	~11,000*
Wanda	1962	1.77	3.96	183

+ estimated by numerical model * according to press reports

^ based on tide pole observations, field surveys or reports of local residents. The operation of tide gauge network in Hong Kong started in 1952.

Number of casualities (including missing persons) caused by Tropical Cyclones in Hong Kong from 1960 to 2015



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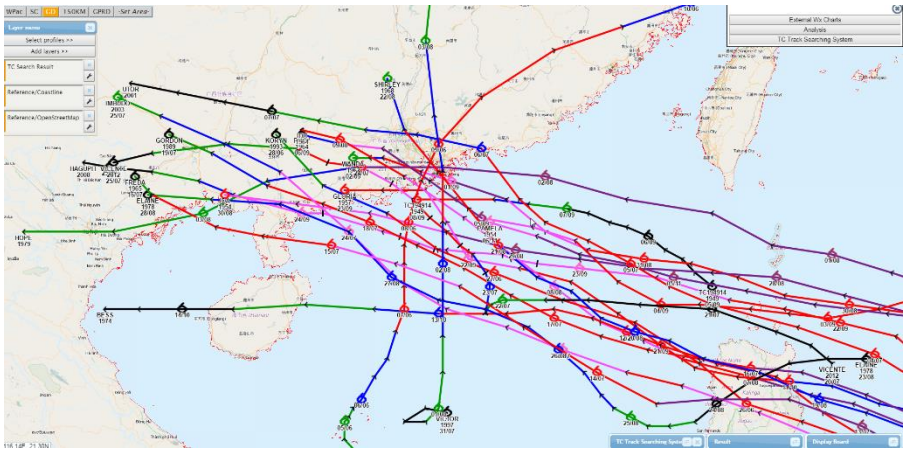
Characteristics of storm surges in Hong Kong

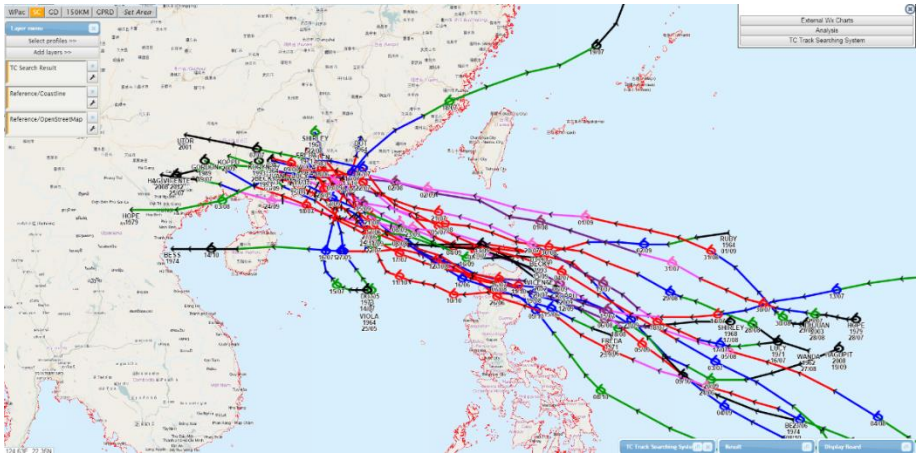
Characteristics of storm surges in Hong Kong

Direction of TC to Hong Kong	N	S	W	Direct hit
Subtotal	3	14	2	1
Mean storm surge(m)	1.18	1.29	1.06	1.09



Tracks of 20 tropical cyclones causing highest storm surges at Quarry Bay

Direction of TC to Hong Kong	N	S	W	E	Direct hit
Subtotal	4	13	1	2	1
Mean storm surge(m)	1.92	1.55	1.4	1.37	1.78



Tracks of 20 tropical cyclones causing highest storm surges at Tai Po Kau

* In Hong Kong, most storm surges would have a height of 0.5 to 1.0 metre.

* In extreme conditions, the water level could exceed the tide level by more than 3 metres, bringing sea flooding to coastal low lying areas.

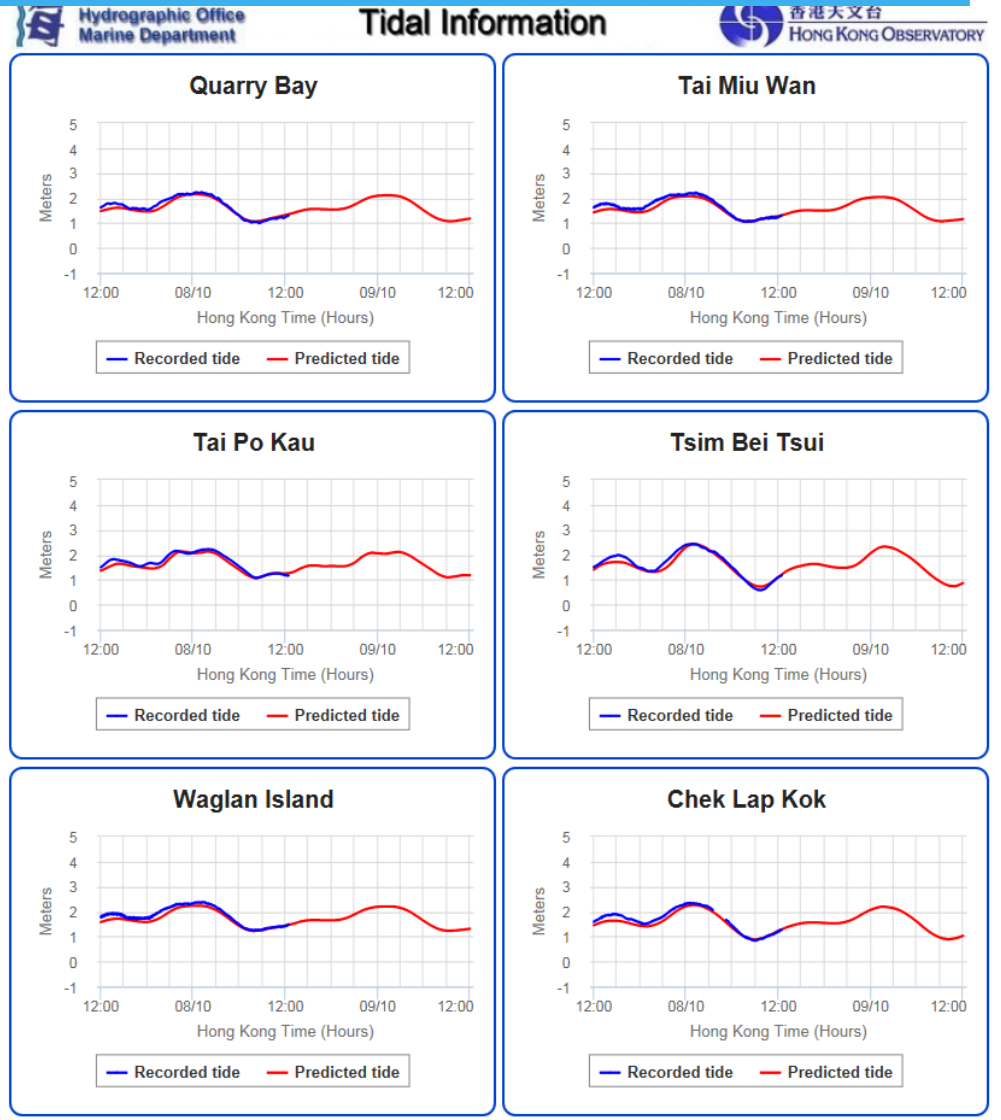
* Storm surges higher:
  Quarry Bay : TC to the S of HK
  Tai Po Kau : TC to the N of HK

Storm surge Monitoring

To monitor and warn storm surge, the following information is required:

* real-time sea level data;
* predicted astronomical tides;
* predicted storm surges.

Real time tide gauge network in Hong Kong



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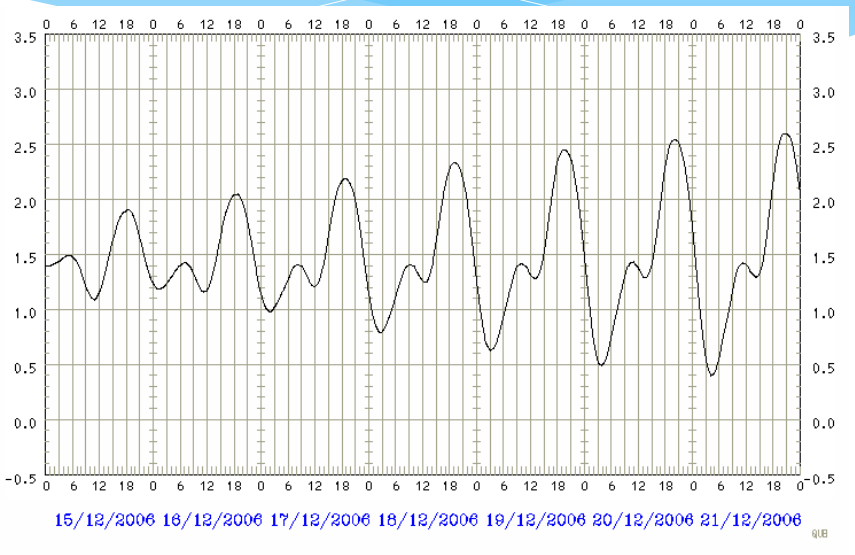
Predicted astronomical tides

Based on the tidal records, the Observatory prepares tidal predictions for the tide gauge stations by applying a harmonic analysis of the data.



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Storm Surge Prediction

SLOSH (Sea, Lake and Overland Surge from Hurricane)

- It is a computerized model developed by the National Weather Service (NWS) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.

- Determining the potential surge for a location

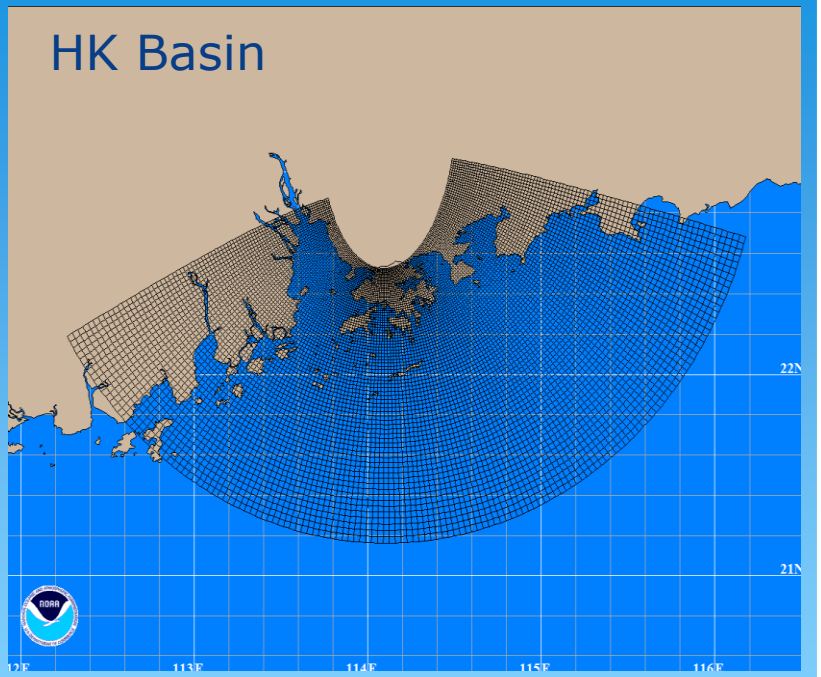
- Adopted at HKO since 1994

SLOSH - Hong Kong Basin

- Topography
- Bathymetry

Input to SLOSH includes 6-hourly values from 48-hr before to 24-hr after time of closest approach to HK (13 points) of the following:

- TC latitude and longitude
- TC min. central pressure
- storm size (Radius of maximum winds)
- Tide offset



Resolution: 1 km near coast, 7 km open sea

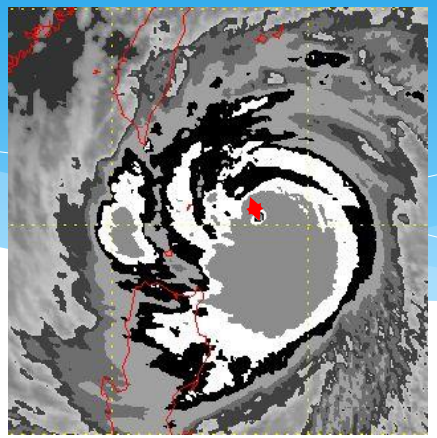
Output

- Storm Surge- Display period from 18 hours before and up to 24 hours after the time of closest approach of TC

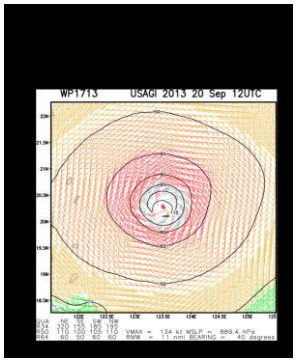
Accuracy – generally within ± 20 % of peak storm surge

Radius of maximum winds (Storm size)

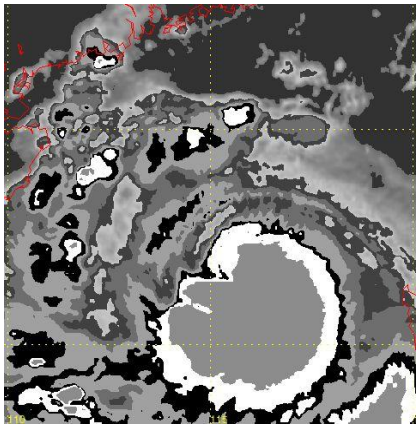
* Radius of maximum winds (r)
  * distance from TC centre to location of maximum winds. In well-developed TCs, the radius of maximum winds is generally found at the inner edge of the eyewall.
  * "r" may be estimated from EIR images or NOAA Multiplatform Satellite Surface Wind Analysis. Uncertain for cases with no eye.



SuperT Usagi
1132Z 20 Sep 2013
(20.2N 123.7E)
(r ~ 0.2 deg. lat.,
but subjective)



NOAA RAMMB Multiplatform
Satellite Surface Wind Analysis



T. Rammasun
2332Z 16 Jul 2014
(16.4N 115.8E),
no eye

Factors that influence Storm Surge

- Central Pressure – minimal contributor
- Storm Intensity
- Size – a larger storm will produce higher surge
- Storm Forward Speed – a faster storm will produce higher surge
- Angle of Approach – move onshore perpendicular to the coast is more likely to produce higher surge
- Shape of the Coastline – landfall on a concave coastline will produce higher surge
- Width and Slope of the Ocean Bottom –
  - wide and gentle sloping continental shelves
  - will produce high surge

Locations for which storm surges are estimated by the SLOSH

SLOSH products

SIMULATED STORM SURGES IN METERS FOR TESTUTOR (JUL 2001)

DAY HOUR (LOCAL)	STATION CODE									
	CLK	CMW	KLW	LOP	MAC	QUB	TAO	TBT	TPK	WAG
317	.61	.62	.67	.59	.61	.63	.62	.54	.68	.70
318	.61	.62	.65	.59	.60	.63	.62	.54	.69	.70
319	.60	.61	.64	.58	.59	.62	.61	.54	.66	.71
320	.59	.61	.66	.57	.58	.62	.61	.53	.64	.73
321	.59	.61	.68	.56	.57	.63	.61	.51	.64	.75
322	.59	.61	.69	.56	.56	.63	.61	.49	.67	.77
323	.58	.60	.71	.55	.55	.64	.60	.47	.69	.80
324	.58	.61	.76	.54	.53	.65	.60	.46	.71	.86
401	.58	.62	.84	.54	.51	.69	.60	.44	.74	.93
402	.58	.64	.94	.54	.48	.74	.61	.42	.81	1.02
403	.60	.65	1.05	.55	.45	.78	.62	.40	.91	1.09
404	.62	.63	1.11	.57	.41	.79	.62	.40	1.01	1.10
405	.63	.58	1.10	.59	.35	.77	.60	.42	1.06	1.06
406	.63	.53	1.09	.60	.26	.75	.55	.46	1.02	1.00
407	.62	.54	1.14	.63	.17	.79	.51	.52	.94	.94
408	.64	.59	1.12	.70	.10	.86	.50	.64	.90	.89
409	.70	.65	.97	.78	.07	.89	.52	.85	.84	.84
410	.74	.69	.88	.84	.12	.89	.56	1.08	.70	.79
411	.78	.70	.91	.88	.19	.85	.61	1.24	.62	.75
412	.81	.70	.86	.90	.27	.82	.65	1.31	.68	.72
413	.82	.69	.76	.89	.34	.78	.67	1.31	.73	.68
414	.81	.66	.70	.87	.41	.72	.67	1.26	.70	.63
415	.78	.61	.64	.82	.44	.65	.65	1.19	.63	.58
416	.73	.56	.56	.77	.46	.60	.62	1.11	.57	.54
417	.69	.53	.51	.71	.46	.55	.58	1.03	.50	.51
418	.64	.51	.52	.67	.46	.53	.56	.95	.47	.50
419	.61	.50	.51	.63	.46	.51	.54	.88	.47	.48
420	.58	.47	.47	.60	.46	.48	.51	.82	.48	.46
421	.55	.44	.45	.56	.45	.45	.49	.76	.46	.45
422	.52	.44	.46	.53	.44	.45	.47	.72	.43	.45
MAX	.82	.70	1.14	.90	.61	.89	.67	1.31	1.06	1.10

FILENAME: TESTUTOR.tab

SIMULATED STORM SURGES + ASTRONOMICAL TIDE IN METERS FOR TESTUTOR (JUL 2001)

DAY HOUR (LOCAL)	STATION CODE									
	CLK	CMW	KLW	LOP	MAC	QUB	TAO	TBT	TPK	WAG
317	1.16	1.40	1.46	1.14	1.16	1.41	1.20	.94	1.51	1.59
318	1.38	1.56	1.49	1.36	1.37	1.55	1.45	1.16	1.54	1.70
319	1.59	1.70	1.62	1.57	1.58	1.68	1.65	1.48	1.59	1.85
320	1.78	1.84	1.84	1.76	1.77	1.84	1.82	1.77	1.77	2.01
321	1.91	1.91	1.97	1.88	1.89	1.93	1.93	1.95	1.93	2.11
322	1.96	1.92	1.95	1.93	1.93	1.93	1.96	2.04	1.93	2.12
323	1.90	1.83	1.88	1.87	1.87	1.86	1.89	2.01	1.85	2.07
324	1.79	1.73	1.84	1.75	1.74	1.76	1.78	1.88	1.77	2.03
401	1.68	1.67	1.84	1.64	1.61	1.74	1.66	1.68	1.71	2.05
402	1.61	1.71	1.99	1.57	1.51	1.83	1.60	1.49	1.78	2.21
403	1.69	1.89	2.36	1.64	1.54	2.08	1.67	1.39	2.10	2.51
404	1.90	2.15	2.78	1.85	1.69	2.37	1.91	1.45	2.64	2.81
405	2.21	2.41	3.00	2.17	1.93	2.64	2.23	1.74	2.99	3.04
406	2.54	2.60	3.06	2.51	2.17	2.81	2.53	2.20	3.04	3.13
407	2.77	2.71	3.13	2.78	2.32	2.93	2.72	2.72	2.94	3.13
408	2.93	2.78	3.18	2.99	2.39	3.04	2.81	3.15	2.94	3.10
409	2.98	2.78	3.05	3.06	2.35	3.01	2.78	3.42	2.95	2.99
410	2.89	2.65	2.79	2.99	2.27	2.83	2.65	3.52	2.66	2.77
411	2.67	2.38	2.50	2.77	2.08	2.49	2.39	3.46	2.25	2.43
412	2.33	1.99	2.08	2.42	1.79	2.08	2.02	3.22	1.94	2.03
413	1.92	1.58	1.62	1.99	1.44	1.66	1.58	2.84	1.63	1.63
414	1.51	1.22	1.25	1.57	1.11	1.29	1.17	2.39	1.27	1.29
415	1.18	1.01	1.07	1.22	.84	1.09	.87	1.94	1.01	1.12
416	1.00	.97	1.08	1.04	.73	1.06	.78	1.55	1.05	1.11
417	1.00	1.08	1.18	1.02	.77	1.13	.88	1.31	1.18	1.22
418	1.15	1.27	1.28	1.18	.97	1.29	1.12	1.29	1.25	1.36
419	1.37	1.44	1.34	1.39	1.22	1.42	1.37	1.48	1.29	1.47
420	1.59	1.58	1.47	1.61	1.47	1.56	1.57	1.78	1.42	1.61
421	1.77	1.68	1.66	1.78	1.67	1.68	1.72	2.04	1.63	1.74
422	1.86	1.75	1.76	1.87	1.78	1.75	1.80	2.21	1.72	1.80
MAX	2.98	2.78	3.18	3.06	2.39	3.04	2.81	3.52	3.04	3.13

FILENAME: TESTUTOR.ast

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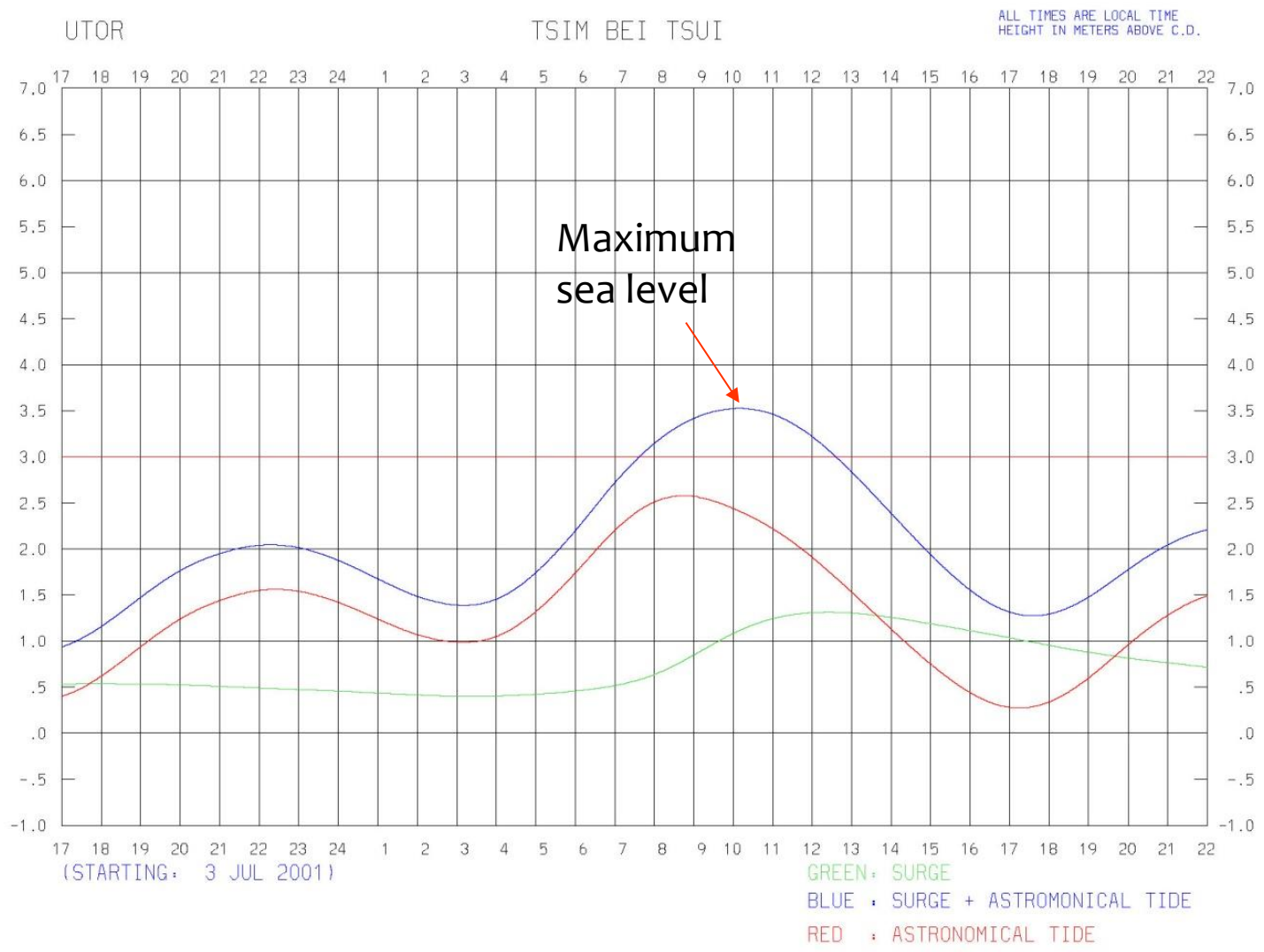
SLOSH products

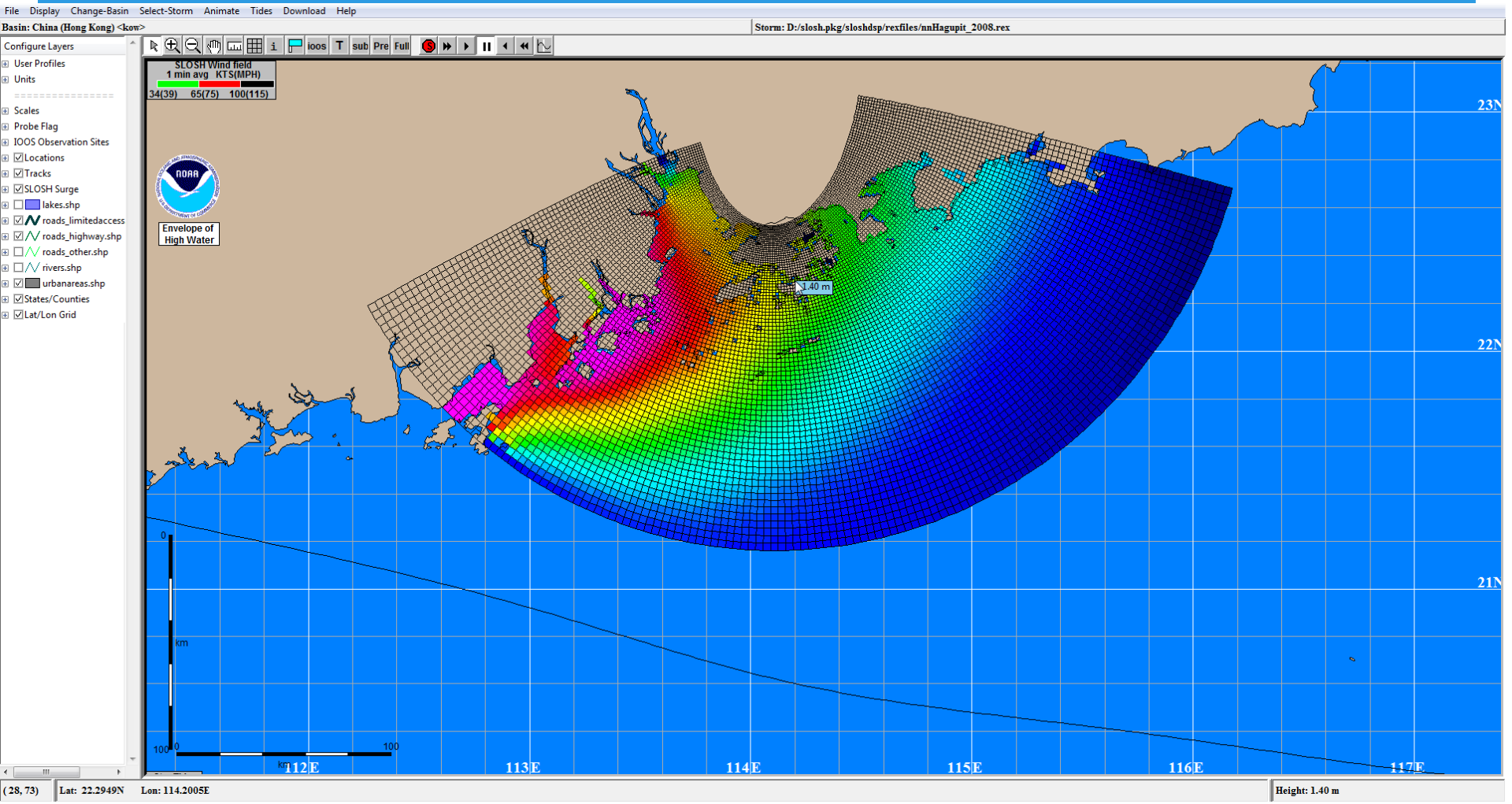


Case study

Severe Typhoon Hagupit (2008)

* Significant storm surge in Hong Kong
* The combined effect of the storm surges of Hagupit and high tides resulted in a maximum sea level of 3.53 metres at Quarry Bay
* The highest since Typhoon Wanda in September 1962.
* At Tai Po Kau, the maximum sea level was 3.77 metres and was the highest there since Typhoon Hope in August 1979.

SLOSH Display Program (NOAA)



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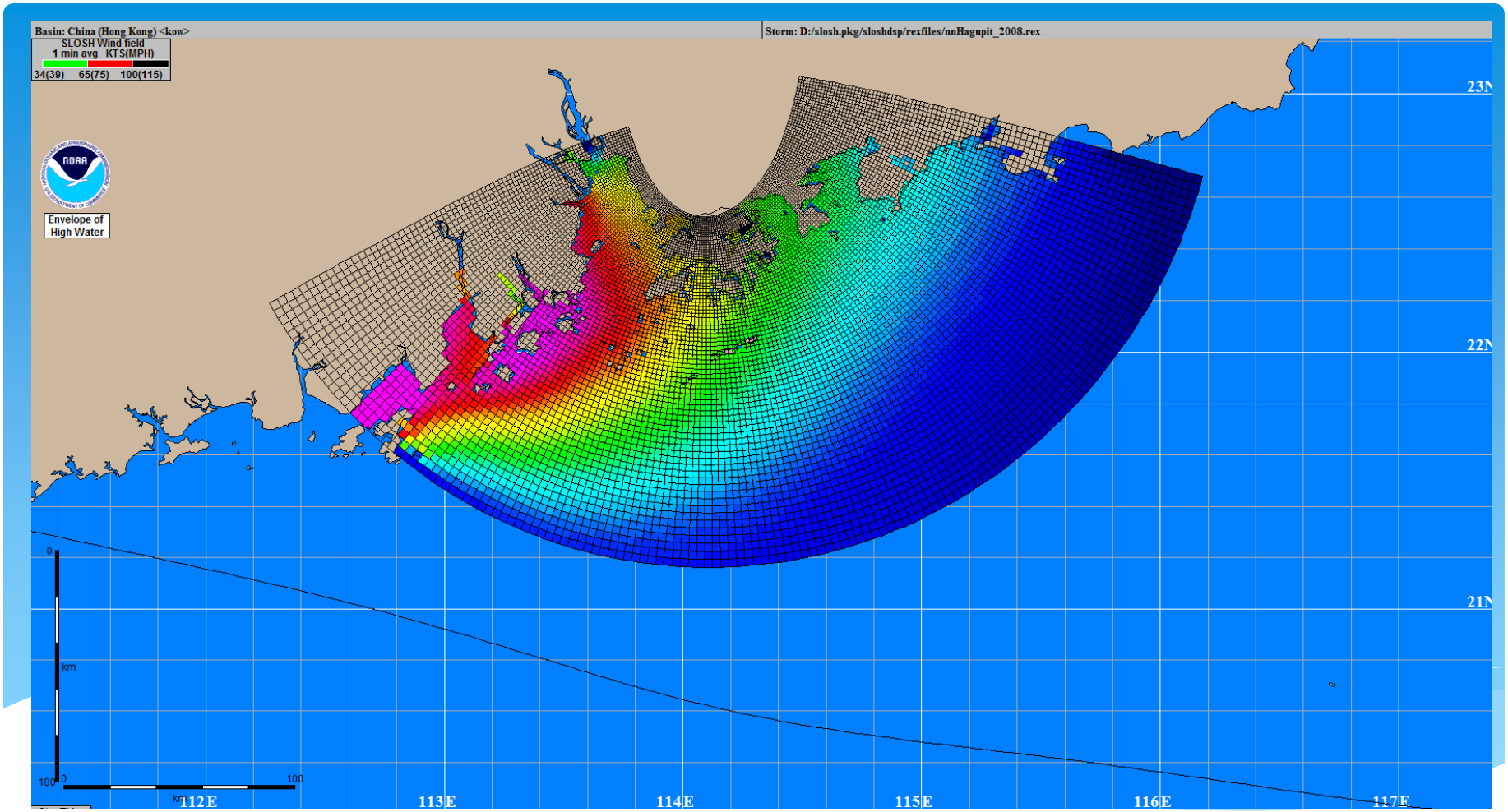
Sea Level in Victoria Harbour during the Passage of Typhoon Hagupit in September 2008



Hagupit 2008

	Recorded	Predicted	Diff	% Error
QUB	1.43	1.40	0.03	2.1
TPK	1.77	1.58	0.19	10.7
TBT	1.46	1.68	-0.22	-15.0

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Verification of SLOSH

SLOSH forecast error =

SLOSH storm surge – actual storm surge

Based on best TC tracks prepared by HKO from the post-storm analysis

Verification results of SLOSH model

Mean	0.04
Standard deviation	0.36
Pearson correlation	0.87
Regression formula	y = 1.2704x - 0.1653
Total	187
Max	1.95
Min	-0.76
RMS	0.37

Statistics on forecast errors of SLOSH storm surge model
(based on the data from 1947 to 2015)

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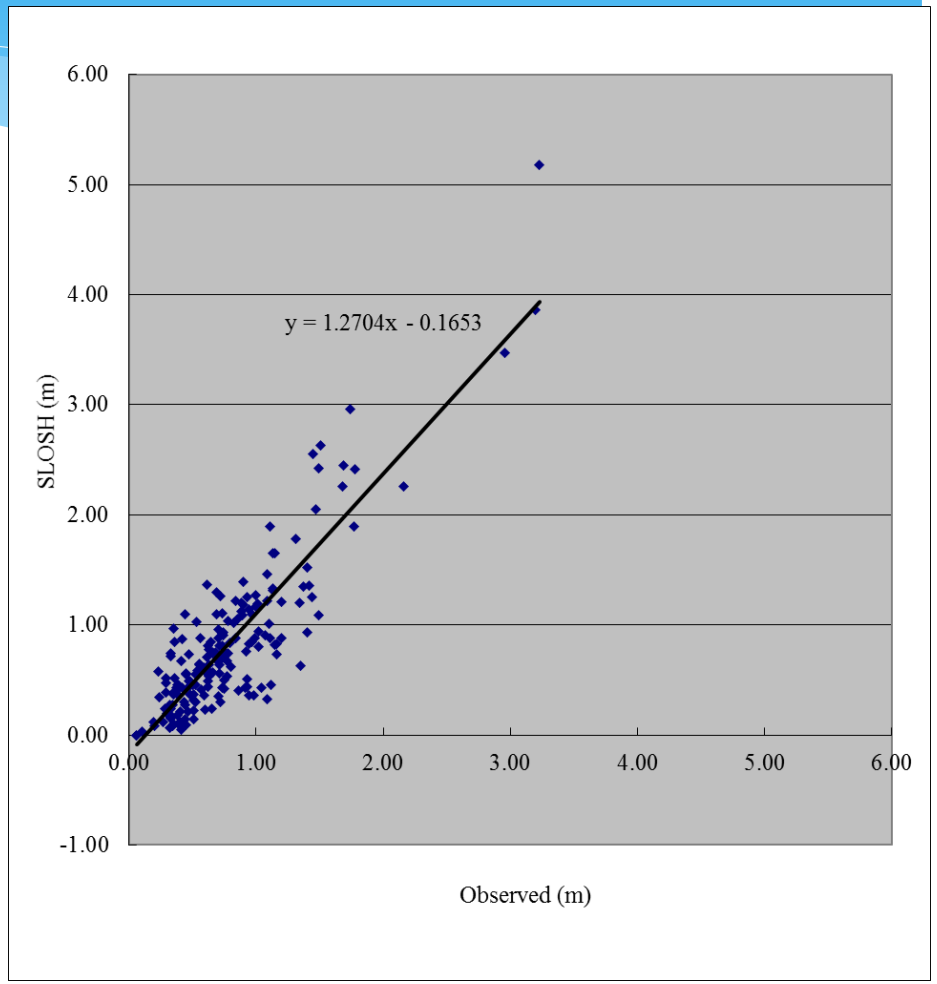
* Simple linear regression equation:
  y = 1.2704x – 0.1653

* Correlation coefficient:
  0.87



Precautions against storm surge

* Stay away from the coast and reach for high ground during the approach of tropical cyclones.
* If you live or work in coastal areas, listen to radio or TV broadcast for warning of high sea levels.
* Contact your nearest police station in emergencies

Summary

* Storm surge: Abnormal rise of sea level and accumulation of sea water near the coast due to tropical cyclone (TC)

* The Observatory has attempted to forecast storm surge since 1960s, used the SLOSH model since 1994 (r.m.s.e. = 0.37 m)

* Higher storm surges:
  1. TC with lower central pressure or faster speed;
  2. TC tracking to the south of HK.

Thank you