# 4-hour Probable Maximum Precipitation (PMP) Updating Study in Hong Kong

## GEO Report No. 331

**B. Lin**

**Geotechnical Engineering Office**
**Civil Engineering and Development Department**
**The Government of the Hong Kong**
**Special Administrative Region**

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# Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet.

W.K. Pun
Head, Geotechnical Engineering Office
October 2017

# Foreword

The Geotechnical Engineering Office (GEO) completed a Probable Maximum Precipitation (PMP) scoping study in 2011 which recommended to carry out a Phase 2 4-hour and 24-hour PMP updating study. Accordingly, the Phase 2 24-hour PMP updating study was completed in 2014, and subsequently the updating of the 4-hour PMP has been undertaken.

In this updating study, the international best practice for the estimation of 4-hour PMP in Hong Kong has been adopted and the study covers storm areas ranging from 10 $km^2$ to about 2,600 $km^2$ with storm transposition and orographic adjustments in addition to the moisture maximisation approach. As part of the study, a statistical approach has been used to obtain an estimation of 4-hour PMP for benchmarking the corresponding value using the storm transposition approach. The new 4-hour PMP has been compared with the master Depth-Area-Duration (DAD) of Hong Kong, as well as world rainfall records.

Professor LIN Bing-zhang of Applied Hydrometeorological Research Institute of the Nanjing University of Information Science & Technology was commissioned by the GEO to undertake this study. Mr Vincent M. Tong and Dr Raymond P.H. Law of the GEO provided technical and administrative support in the study. The study was overseen by the 4-hour PMP Updating Study Working Group, comprising Dr H.W. Sun as the chairman, and Mr Vincent M. Tong and Ms Rachel H.C. Law of the GEO, Dr T.C. Lee of Hong Kong Observatory, Mr Y.F. Tam of Drainage Services Department, Mr Y.H. Tam of Water Supplies Department, Dr J. Chen of the University of Hong Kong and Dr Andy Y.F. Leung of the Hong Kong Institution of Engineers as the members. All contributions are gratefully acknowledged.

J.S.H. Kwan
Chief Geotechnical Engineer/Standards & Testing

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# 1 Introduction

## 1.1 Background

In 2000, the Hong Kong Observatory (HKO) conducted a Phase 1 4-hour Probable Maximum Precipitation (PMP) Updating Study based on local rainstorm data from 1955 to 2000. Subsequently, the GEO completed a PMP scoping study in the year 2011 which recommended that a Phase 2 PMP updating study should be carried out. The updating study shall adopt the international best practice to update the 4-hour and 24-hour PMP estimates for Hong Kong.

In 2014, the Geotechnical Engineering Office (GEO) completed the updating of the 24-hour PMP in Hong Kong under the Phase 2 PMP updating study. The 24-hour PMP estimate in Hong Kong was updated using the international best practice and the study covered storm areas ranging from 10 $km^2$ to about 2,600 $km^2$ with storm transposition and orographic adjustments in addition to the moisture maximisation approach. Moreover, a statistical approach was adopted to obtain an estimation of 24-hour PMP for benchmarking the corresponding value using the storm transposition approach. Details of the Phase 2 24-hour PMP updating study are documented in AECOM & Lin (2015).

In late 2015, Professor LIN Bing-zhang of Applied Hydrometeorological Research Institute, The Nanjing University of Information Science & Technology was commissioned by the GEO to undertake the Phase 2 4-hour PMP updating study. The study methodology followed that of the 24-hour PMP updating study in 2014, with due consideration of the newly available meteorological data of recent extreme rainfall events in relatively short duration. The study was completed in 2017.

This report documents the meteorological data reviewed, the study methodology as well as the findings of the Phase 2 4-hour PMP updating study.

## 1.2 Scope of the Study

To facilitate the study, the following tasks were set out and undertaken in stages:

(a) Submit an Inception Report to briefly describe the study approach and data requirements;

(b) Liaise with relevant authorities to collect all required information and meteorological data;

(c) Set the storm selection criteria for both local and non-local storms for use in 4-hour PMP updating;

(d) Carry out storm transposition analysis for the selected non-local storm using storm separation technique (Step-Duration-Orographic-Intensification-Factors (SDOIF) method);

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(e) Carry out transposition adjustment for non-local storms with respect to moisture maximisation, storm orientation and orographic adjustment;

(f) Obtain an estimation of 4-hour PMP by statistical approach;

(g) Carry out Depth-Area-Duration (DAD) analysis for producing 4-hour updated PMP and comparison with previous 4-hour PMPs; and

(h) Evaluation of PMP estimates in comparison with historical rainfall records and PMP estimates in other comparable areas.

# 2 Approach and Methodology

## 2.1 Statistical Method

The methods available for PMP estimation are mainly in two ways: meteorological estimation methods and statistical method for the world's popular practice (WMO, 2009). Statistical method is basically a frequency analysis but different from traditional frequency analysis in such a way that the number of standard deviation $K_m$, to be added (to be multiplied actually) to the mean to get the PMP in the frequency equation is to be calculated in a unique way that the maximum observed value from the historical series will be omitted in the computation.

This statistical estimation is particularly useful for making quick estimates of PMP. Obviously, the longer data series with outstanding extreme value recorded is welcomed for the method. The results of the PMP estimates from the statistical approach may be of value in comparison with the results obtained from the traditional storm transposing approach which is the core of this 4-hour PMP updating study.

Detailed discussions of the formulation and procedures of the statistical method are given in Section 1.3.1 of AECOM & Lin (2015).

## 2.2 Storm Transposition Approach Using the Step Duration Orographic Intensification Factor (SDOIF) Method

### 2.2.1 Overview

The storm transposition used to be restricted to regions that are meteorologically and topographically homogeneous where storms that have been observed are considered to be equally likely to occur. The transposition was undertaken based on the storm separation technique (i.e. SDOIF) developed by B. Lin during the PMP Estimation of Daguangba Project (林炳章, 1988; Lin, 1988) on Hainan Island of China. The SDOIF method was recommended by World Meteorological Organization (WMO) in its Third Version of Manual on Estimation of PMP (WMO, 2009) for PMP estimation in mountainous regions. The storm separation technique separates mountainous storm rainfall into components caused by

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atmospheric forcing and those caused by terrain forcing. This method is a combined engineering hydrologic-meteorological approach based on long-term rainfall statistics, synoptic analysis of storms and topographic features in a gridded design area. Thus, it may be assumed that one can transpose the atmospheric force (referred as convergence or non-orographic) component within a mountainous region in a larger area. Then, the transposed convergence component can be merged with the designed local terrain force (referred as orographic) component to make a PMP estimate for the designed mountainous areas. The concepts of storm transposition and the storm separation technique of SDOIF are considered to be applicable to the PMP estimation for Hong Kong.

Unlike consideration of a general weather analysis or synoptic analysis for a given region that may require going over different synoptic patterns, the major concern for a PMP study is the rainfall intensity at a given duration for a given location or a design area. The guide to select a target storm for transposition in PMP study is mainly based on the severity (i.e. rainfall intensity for 4-hour and other short durations such as 1-hour and/or 6-hour) and spatial coverage to distinguish local convective storms and other types of storms with respect to PMP estimation for this updating study.

Detailed discussions of the formulation and procedures of the SDOIF method are given in Section 1.3.2 of AECOM & Lin (2015).

# 3 Data

## 3.1 Rainfall Data

Historical Annual Maximum Series rainfall (AMS) data were used in the statistical method and storm transposition together with storm data to obtain the PMP estimates.

(1) Taiwan

The 4-hour historical annual maximum rainfall series of 55 Water Resources Agency (WRA) raingauge stations and historical hourly data of 11 Central Weather Bureau (CWB) raingauge stations of Taiwan purchased from Taiwan were used in the computation of the Orographic Intensification Factors (OIF). Data information of the 66 raingauge stations are shown in Table 3.1. The column of “N-years” in Table 3.1 is the total number of year which has rainfall data record. The observation periods of the raingauge stations in general exceed 30 years. Figure 3.1 shows the geographic locations of the raingauge stations.

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**Table 3.1 Data Information of the 66 Raingauge Stations in Taiwan (Sheet 1 of 2)**

| | No. | Name | Time Period | N-Years |
|---|---|---|---|---|
| WRA | 1 | 雙崎(2) Shuangqi(2) | 1965-2013 | 45 |
| | 2 | 龍神橋 Longshenqiao | 1963-2014 | 44 |
| | 3 | 集集(2) Jiji(2) | 1954-2014 | 50 |
| | 4 | 北港(2) Beigang(2) | 1956-2013 | 49 |
| | 5 | 旗山(4) Qishan(4) | 1961-2014 | 45 |
| | 6 | 屏東(5) Pingdong(5) | 1956-2014 | 48 |
| | 7 | 鹿鳴橋 Lumingqiao | 1962-2013 | 43 |
| | 8 | 林口(1) Linkou(1) | 1974-2013 | 35 |
| | 9 | 火燒寮 Huoshaoliao | 1955-2014 | 50 |
| | 10 | 福山(3) Fushan(3) | 1978-2014 | 35 |
| | 11 | 太閣南 Taigenan | 1965-2013 | 48 |
| | 12 | 橫龍山 Henglongshan | 1972-2014 | 43 |
| | 13 | 大坪頂 Dapingding | 1980-2013 | 33 |
| | 14 | 八仙山(1) Baxianshan(1) | 1989-2013 | 23 |
| | 15 | 雪嶺 Xueling | 1971-2013 | 42 |
| | 16 | 頭汴坑 Toubiankeng | 1969-2013 | 44 |
| | 17 | 萬興(2) Wanxing(2) | 1967-2014 | 44 |
| | 18 | 翠峰 Cuifeng | 1965-2014 | 44 |
| | 19 | 望鄉 Wangxiang | 1961-2014 | 46 |
| | 20 | 卡奈托灣(2) Kanaituowan(2) | 1969-2005 | 31 |
| | 21 | 西巒 Xiluan | 1961-2014 | 45 |
| | 22 | 六分寮 Liufenliao | 1967-2013 | 43 |
| | 23 | 北山(2) Beishan(2) | 1969-2013 | 44 |
| | 24 | 西螺(2) Xiluo(2) | 1961-2014 | 42 |
| | 25 | 林內(1) Linnei(1) | 1961-2013 | 42 |
| | 26 | 大埔 Daupu | 1959-2013 | 42 |
| | 27 | 褒忠(2) Baozhong(2) | 1961-2013 | 42 |
| | 28 | 大湖山 Dauhushan | 1957-2013 | 46 |
| | 29 | 樟腦寮(2) Zhangnaoliao(2) | 1962-2013 | 44 |
| | 30 | 中坑 Zhongkeng(3) | 1962-2013 | 45 |
| | 31 | 關子嶺(2) Guanziling(2) | 1959-2014 | 43 |
| | 32 | 木柵 Mushan | 1959-2014 | 44 |
| | 33 | 阿蓮(2) Ahlian(2) | 1961-2014 | 40 |

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**Table 3.1 Data Information of the 66 Raingauge Stations in Taiwan (Sheet 2 of 2)**

| | No. | Name | Time Period | N-Years |
|---|---|---|---|---|
| WRA | 34 | 甲仙(2) Jiaxian(2) | 1957-2014 | 47 |
| | 35 | 新豐 Xinfeng | 1957-2009 | 38 |
| | 36 | 泰武(1) Taiwu(1) | 1958-2014 | 44 |
| | 37 | 南和 Nanhe | 1965-2014 | 45 |
| | 38 | 阿禮 Ahli | 1967-2014 | 45 |
| | 39 | 三地門 Sandimen | 1967-2014 | 44 |
| | 40 | 知本(5) Zhiben(5) | 1980-2013 | 34 |
| | 41 | 紹家 Shaojia | 1957-2013 | 49 |
| | 42 | 霧鹿 Wulu | 1957-2013 | 45 |
| | 43 | 新武(3) Xinwu(3) | 1973-2013 | 39 |
| | 44 | 向陽(2) Xiangyang(2) | 1973-2013 | 41 |
| | 45 | 卓麓(4) Zhuolu(4) | 1972-2013 | 39 |
| | 46 | 立山 Lishan | 1959-2014 | 43 |
| | 47 | 西林 Xilin | 1974-2014 | 37 |
| | 48 | 哇拉鼻 Walabi | 1981-2013 | 33 |
| | 49 | 馬太安 Mataian | 1980-2014 | 34 |
| | 50 | 南山 Nanshan | 1963-2014 | 41 |
| | 51 | 大濁水 Dazhuoshui | 1980-2014 | 35 |
| | 52 | 武塔 Wuta | 1979-2014 | 35 |
| | 53 | 藤枝(2) Tengzhi(2) | 1980-2010 | 31 |
| | 54 | 天池 Tianchi | 1978-2014 | 37 |
| | 55 | 民族 Minzu | 1978-2009 | 32 |
| CWB | 56 | 永康 Yongkang | 1998-2015 | 18 |
| | 57 | 高雄 Gaoxiong | 1982-2015 | 34 |
| | 58 | 玉山 Yushan | 1982-2015 | 34 |
| | 59 | 阿里山 Ahlishan | 1982-2015 | 34 |
| | 60 | 花蓮 Hualian | 1982-2015 | 34 |
| | 61 | 宜蘭 Yilan | 1982-2015 | 34 |
| | 62 | 恆春 Hengchun | 1982-2015 | 34 |
| | 63 | 臺東 Taidong | 1982-2015 | 34 |
| | 64 | 樸子 Puzi | 1993-2014 | 22 |
| | 65 | 北門 Beimen | 1993-2014 | 22 |
| | 66 | 下營 Xiaying | 1993-2014 | 22 |


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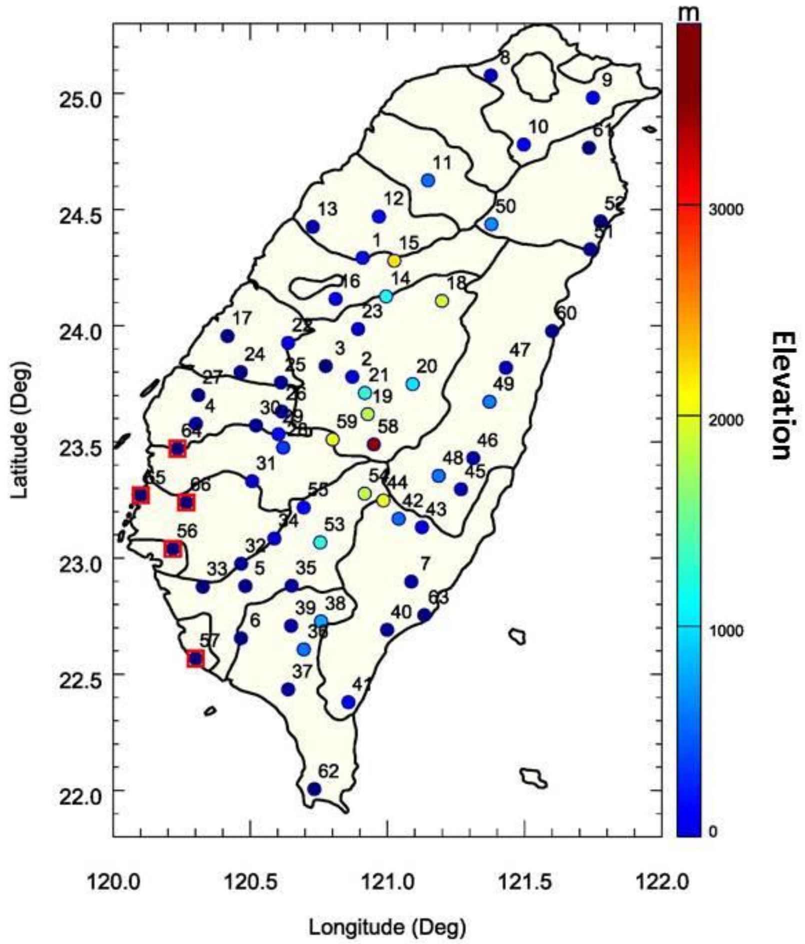


| Note: | Stations with the red frame are used for calculating rainfall without the orographic influence, $r_0$. |
|---|---|

**Figure 3.1 Locations of the 66 Raingauge Stations in Taiwan**

(2) Hong Kong

The rainfall data obtained from 48 raingauge stations of HKO (in 1-min interval) and 88 raingauge stations from GEO (in 5-min interval) for different time periods were reviewed in this study. Also, the hourly data of HKO Headquarters raingauge (HKO HQ) for the period between 1984 and 2015 were also studied. The details of those raingauge stations are given in Table 3.2, and the locations of those raingauge stations are shown in Figure 3.2.

**Table 3.2 Data Information of 136 Raingauge Stations in Hong Kong (Sheet 1 of 2)**

| No. | ID | Time Period | N-Years | Interval | No. | ID | Time Period | N-Years | Interval |
|---|---|---|---|---|---|---|---|---|---|
| 1 | H01 | 1984-2015 | 31 | 5-min | 69 | N34 | 1999-2015 | 16 | 5-min |
| 2 | H02 | 1984-2015 | 32 | 5-min | 70 | N35 | 1999-2015 | 16 | 5-min |
| 3 | H03 | 1984-2015 | 32 | 5-min | 71 | N36 | 1999-2015 | 16 | 5-min |
| 4 | H04 | 1984-2015 | 32 | 5-min | 72 | N37 | 1999-2015 | 16 | 5-min |
| 5 | H05 | 1984-2015 | 32 | 5-min | 73 | N38 | 1999-2015 | 16 | 5-min |
| 6 | H06 | 1984-2015 | 32 | 5-min | 74 | N39 | 1999-2015 | 16 | 5-min |
| 7 | H07 | 1984-2015 | 32 | 5-min | 75 | N40 | 1999-2015 | 16 | 5-min |
| 8 | H08 | 1984-2015 | 32 | 5-min | 76 | N41 | 1999-2015 | 16 | 5-min |
| 9 | H09 | 1984-2015 | 32 | 5-min | 77 | N42 | 1999-2015 | 16 | 5-min |
| 10 | H10 | 1984-2015 | 32 | 5-min | 78 | N43 | 1999-2015 | 16 | 5-min |
| 11 | H12 | 1984-2015 | 32 | 5-min | 79 | N44 | 1999-2015 | 16 | 5-min |
| 12 | H14 | 1984-2015 | 32 | 5-min | 80 | N45 | 1999-2015 | 16 | 5-min |
| 13 | H15 | 1984-2015 | 32 | 5-min | 81 | N46 | 1999-2015 | 16 | 5-min |
| 14 | H16 | 1984-2015 | 32 | 5-min | 82 | N47 | 1999-2015 | 16 | 5-min |
| 15 | H17 | 1984-2015 | 32 | 5-min | 83 | N48 | 1999-2015 | 16 | 5-min |
| 16 | H18 | 1984-2015 | 32 | 5-min | 84 | N49 | 1999-2015 | 16 | 5-min |
| 17 | H19 | 1984-2015 | 32 | 5-min | 85 | N50 | 1999-2015 | 16 | 5-min |
| 18 | H20 | 1984-2015 | 32 | 5-min | 86 | N51 | 1999-2015 | 14 | 5-min |
| 19 | H21 | 1984-2015 | 30 | 5-min | 87 | N52 | 2011-2015 | 5 | 5-min |
| 20 | H23 | 1999-2015 | 16 | 5-min | 88 | N53 | 2011-2015 | 5 | 5-min |
| 21 | H24 | 1999-2015 | 16 | 5-min | 89 | R11 | 1984-2015 | 29 | 5-min |
| 22 | H25 | 1999-2015 | 16 | 5-min | 90 | R12 | 1985-2015 | 31 | 5-min |
| 23 | H26 | 1999-2015 | 16 | 5-min | 91 | R14 | 1985-2015 | 31 | 5-min |
| 24 | H28 | 1999-2015 | 16 | 5-min | 92 | R18 | 1985-2015 | 31 | 5-min |
| 25 | H29 | 1999-2015 | 16 | 5-min | 93 | R19 | 1992-2015 | 24 | 5-min |
| 26 | K01 | 1984-2015 | 32 | 5-min | 94 | R21 | 1985-2015 | 31 | 5-min |
| 27 | K02 | 1984-2015 | 32 | 5-min | 95 | R22 | 1985-2015 | 31 | 5-min |
| 28 | K03 | 1984-2015 | 32 | 5-min | 96 | R23 | 1985-2015 | 31 | 5-min |
| 29 | K04 | 1984-2015 | 32 | 5-min | 97 | R24 | 1985-2015 | 31 | 5-min |
| 30 | K05 | 1984-2015 | 32 | 5-min | 98 | R25 | 1985-2015 | 31 | 5-min |
| 31 | K06 | 1984-2015 | 32 | 5-min | 99 | R27 | 1985-2015 | 31 | 5-min |
| 32 | K07 | 1984-2015 | 32 | 5-min | 100 | R28 | 1985-2015 | 31 | 5-min |
| 33 | K08 | 1984-2015 | 32 | 5-min | 101 | R29 | 1985-2015 | 31 | 5-min |
| 34 | K09 | 1999-2015 | 16 | 5-min | 102 | R31 | 1985-2015 | 31 | 5-min |
| 35 | K10 | 1999-2015 | 16 | 5-min | 103 | BR1 | 2006-2015 | 10 | 1-min |
| 36 | N01 | 1984-2015 | 32 | 5-min | 104 | CCH | 1992-2015 | 24 | 1-min |
| 37 | N02 | 1984-2015 | 32 | 5-min | 105 | CPH | 1987-2015 | 14 | 1-min |

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**Table 3.2 Data Information of 136 Raingauge Stations in Hong Kong (Sheet 2 of 2)**

| No. | ID | Time Period | N-Years | Interval | No. | ID | Time Period | N-Years | Interval |
|---|---|---|---|---|---|---|---|---|---|
| 38 | N03 | 1984-2015 | 32 | 5-min | 106 | EPC | 1993-2015 | 23 | 1-min |
| 39 | N04 | 1984-2015 | 32 | 5-min | 107 | GI | 1989-2015 | 11 | 1-min |
| 40 | N05 | 1984-2015 | 32 | 5-min | 108 | HKA | 1997-2015 | 10 | 1-min |
| 41 | N06 | 1984-2015 | 32 | 5-min | 109 | HKO HQ | 1884-2015 | 125 | 1-hour |
| 42 | N07 | 1984-2015 | 32 | 5-min | 110 | HPV | 2008-2015 | 8 | 1-min |
| 43 | N08 | 1984-2015 | 32 | 5-min | 111 | JKB | 1991-2015 | 25 | 1-min |
| 44 | N09 | 1984-2015 | 32 | 5-min | 112 | KAT | 1993-2015 | 18 | 1-min |
| 45 | N10 | 1984-2015 | 32 | 5-min | 113 | KFB | 2010-2015 | 6 | 1-min |
| 46 | N11 | 1984-2015 | 32 | 5-min | 114 | KP | 1992-2015 | 24 | 1-min |
| 47 | N12 | 1984-2015 | 32 | 5-min | 115 | KSC | 2008-2015 | 8 | 1-min |
| 48 | N13 | 1984-2015 | 32 | 5-min | 116 | LAM | 2011-2015 | 5 | 1-min |
| 49 | N14 | 1984-2015 | 32 | 5-min | 117 | LFS | 1985-2015 | 31 | 1-min |
| 50 | N15 | 1984-2015 | 32 | 5-min | 118 | PEN | 2004-2015 | 12 | 1-min |
| 51 | N16 | 1985-2015 | 31 | 5-min | 119 | PLC | 1993-2015 | 23 | 1-min |
| 52 | N17 | 1991-2015 | 25 | 5-min | 120 | SE | 1995-2015 | 7 | 1-min |
| 53 | N18 | 1991-2015 | 25 | 5-min | 121 | SEK | 1996-2015 | 20 | 1-min |
| 54 | N19 | 1999-2015 | 16 | 5-min | 122 | SHA | 1984-2015 | 32 | 1-min |
| 55 | N20 | 1999-2015 | 16 | 5-min | 123 | SKW | 2007-2015 | 9 | 1-min |
| 56 | N21 | 1999-2015 | 16 | 5-min | 124 | SLW | 1993-2015 | 23 | 1-min |
| 57 | N22 | 1999-2015 | 16 | 5-min | 125 | SSH | 2004-2015 | 12 | 1-min |
| 58 | N23 | 1999-2015 | 16 | 5-min | 126 | SSP | 2010-2015 | 6 | 1-min |
| 59 | N24 | 1999-2015 | 16 | 5-min | 127 | TAP | 1993-2015 | 23 | 1-min |
| 60 | N25 | 1999-2015 | 16 | 5-min | 128 | TC | 1987-2015 | 19 | 1-min |
| 61 | N26 | 1999-2015 | 16 | 5-min | 129 | TKL | 1988-2015 | 28 | 1-min |
| 62 | N27 | 1999-2015 | 16 | 5-min | 130 | TMS | 1987-2015 | 19 | 1-min |
| 63 | N28 | 1999-2015 | 16 | 5-min | 131 | TUL | 2006-2015 | 10 | 1-min |
| 64 | N29 | 1999-2015 | 16 | 5-min | 132 | TWN | 2006-2015 | 10 | 1-min |
| 65 | N30 | 1999-2015 | 16 | 5-min | 133 | TYW | 1995-2015 | 21 | 1-min |
| 66 | N31 | 1999-2015 | 16 | 5-min | 134 | VPL | 2003-2015 | 12 | 1-min |
| 67 | N32 | 1999-2015 | 16 | 5-min | 135 | WGL | 1989-2015 | 27 | 1-min |
| 68 | N33 | 1999-2015 | 16 | 5-min | 136 | WLP | 2005-2015 | 11 | 1-min |

Note: The rainfall data for the 136 raingauge stations up to June 2016 were collected from the HKO and reviewed.

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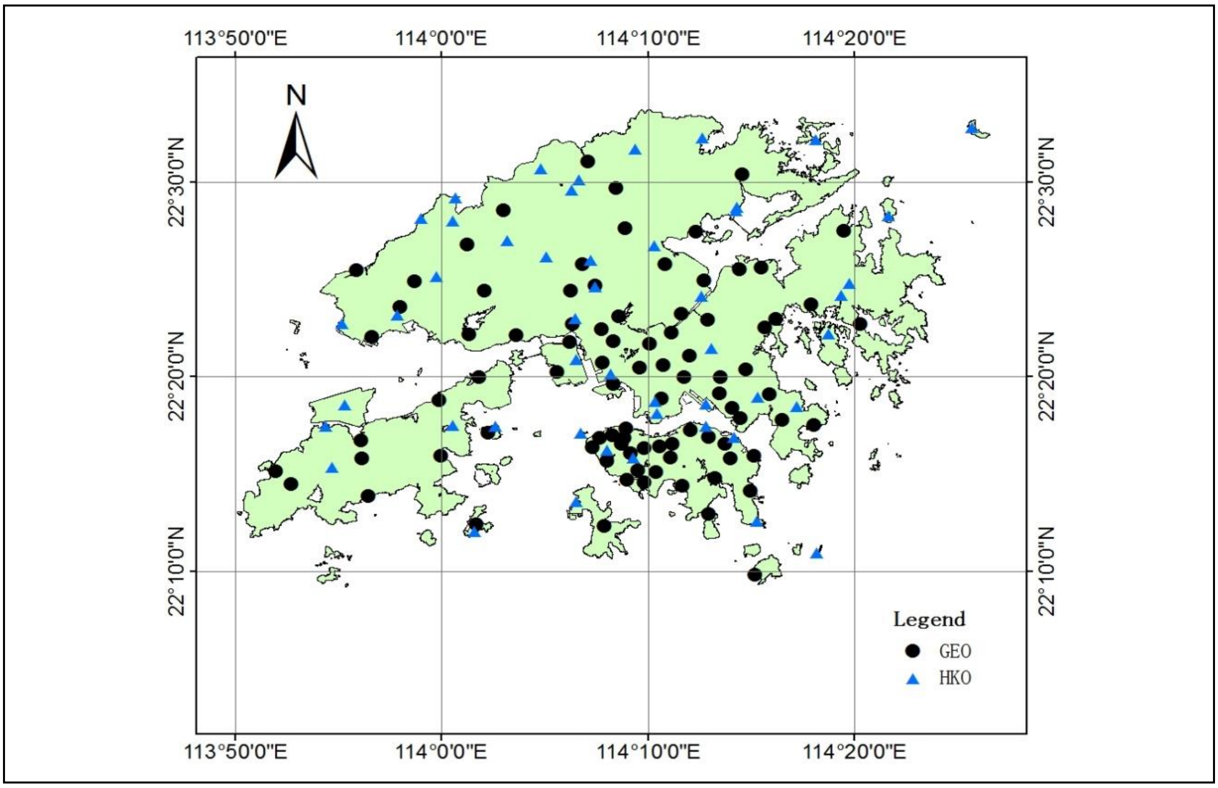


**Figure 3.2 Locations of Raingauge Stations in Hong Kong**

(3) South Guangdong

A total of five raingauge stations located in the South of Guangdong Province with available historical annual maximum 4-hour rainfall series were obtained from the Guangdong Hydrological Bureau (GD HB) in 2012. The annual maximum 4-hour rainfall data have not been regularly compiled by the GD HB after 2005. Therefore, the data after 2005 were not available for this updating study. The raingauge stations in South Guangdong and their mean annual maximum rainfall are given in Table 3.3. The locations of the 5 raingauge stations are given in Figure 3.3.

**Table 3.3 4-hour Mean Annual Maximum Rainfalls of 5 Raingauge Stations in South of Guangdong**

| No. | Name | Longitude | Latitude | Time Period | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|
| 1 | 惠陽 Huiyang | 114.40 | 23.10 | 1971-2005 | 87.66 |
| 2 | 港口 Gangkou | 114.90 | 22.57 | 1975-2005 | 119.38 |
| 3 | 深圳 Shenzhen* | 114.10 | 22.55 | 1981-2005 | 111.86 |
| 4 | 南澳嶼 Nanaoyu | 114.48 | 22.53 | 1982-2005 | 125.60 |
| 5 | 約場 Yuechang | 114.25 | 22.85 | 1971-1989 | 115.84 |

Note: * Base stations selected for development of SDOIF (refer to Figure 6.1).

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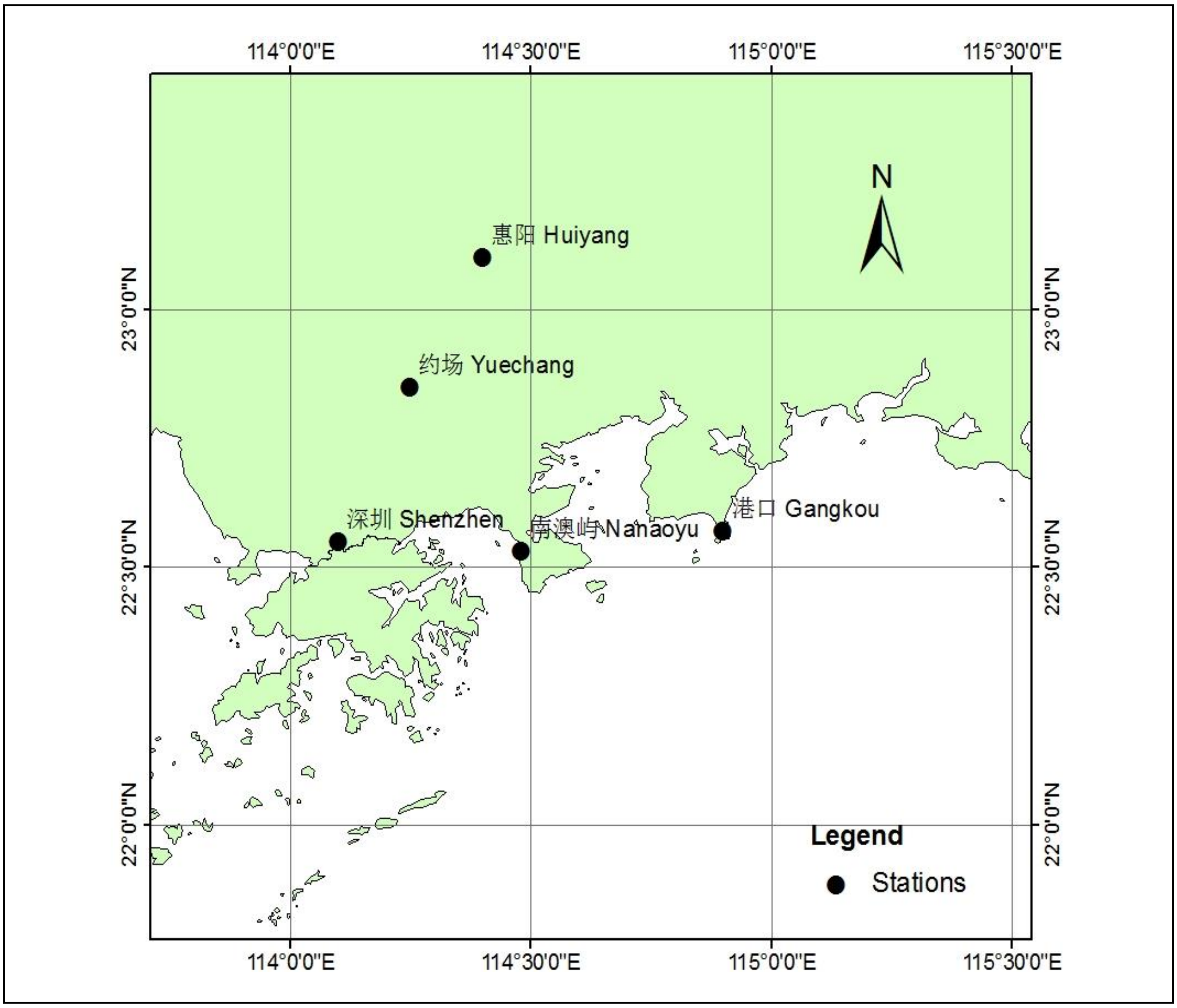


**Figure 3.3 Locations of 5 Raingauge Stations in South of Guangdong**

(4) Macau

Hourly data of Macau raingauge stations between 1952 and 2015 were provided by the Macao Meteorological and Geophysical Bureau in 2016. The raingauge stations were located at Colina da Guia (東望洋山) between 1952 and 1966. The raingauge stations were subsequently relocated to Monte Forte (大炮臺山) between 1966 and 1996. In August 1996, the raingauge station was relocated to Taipa Grande (大潭山).

### 3.1.1 Dew Point Data

Hourly dew point data of HKO HQ from 1884 to 2015 provided by HKO were analysed in this study. In addition, hourly dew point data of other 27 stations from 1984 to 2015 with different series were also used in the study. The details of the 28 stations in total are listed in Table 3.4. The locations of the dew point stations are shown in Figure 9.6.

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**Table 3.4 Information of Dew Point Stations in Hong Kong**

| No. | Name | Abb. | Longitude | Latitude | Elevation (m) | Start Year | N-Years |
|---|---|---|---|---|---|---|---|
| 1 | Hong Kong Observatory | HKO | 114.17 | 22.30 | 32 | 1884 | 131 |
| 2 | Sha Tin | SHA | 114.21 | 22.40 | 6 | 1984 | 31 |
| 3 | Lau Fau Shan | LFS | 113.98 | 22.47 | 31 | 1985 | 30 |
| 4 | Ta Kwu Ling | TKL | 114.16 | 22.53 | 15 | 1988 | 27 |
| 5 | Wong Chuk Hang | HKS | 114.17 | 22.25 | 5 | 1989 | 26 |
| 6 | Waglan Island | WGL | 114.30 | 22.18 | 56 | 1989 | 26 |
| 7 | Tseung Kwan O | JKB | 114.26 | 22.31 | 38 | 1991 | 24 |
| 8 | Cheung Chau | CCH | 114.03 | 22.20 | 72 | 1992 | 23 |
| 9 | King’s Park | KP | 114.17 | 22.31 | 65 | 1992 | 23 |
| 10 | Sha Lo Wan | SLW | 113.91 | 22.29 | 61 | 1993 | 22 |
| 11 | Sai Kung | SKG | 114.27 | 22.38 | 4 | 1993 | 22 |
| 12 | Tsak Yue Wu | TYW | 114.32 | 22.40 | 5 | 1995 | 20 |
| 13 | Hong Kong International Airport | HKA | 113.92 | 22.30 | 6 | 1997 | 18 |
| 14 | Shek Kong | SEK | 114.08 | 22.43 | 16 | 1996 | 19 |
| 15 | Tai Mo Shan | TMS | 114.12 | 22.41 | 955 | 1996 | 19 |
| 16 | Nei Lak Shan (NLS) | NLS | 113.91 | 22.26 | 747 | 2002 | 13 |
| 17 | Tate’s Cairn | TC | 114.22 | 22.36 | 575 | 1998 | 17 |
| 18 | Tai Po | TP | 114.18 | 22.45 | 15 | 1999 | 16 |
| 19 | Ching Pak House, Tsing Yi | CPH | 114.11 | 22.35 | 122 | 2002 | 13 |
| 20 | Peng Chau | PEN | 114.04 | 22.29 | 34 | 2004 | 11 |
| 21 | Sheung Shui | SSH | 114.11 | 22.50 | 10 | 2004 | 11 |
| 22 | Wetland Park | WLP | 114.01 | 22.47 | 4 | 2005 | 10 |
| 23 | Tsuen Wan Ho Koon | TWN | 114.11 | 22.38 | 142 | 2006 | 9 |
| 24 | Tuen Mun Children and Juvenile Home | TU1 | 113.96 | 22.39 | 28 | 2007 | 8 |
| 25 | Kau Sai Chau | KSC | 114.31 | 22.37 | 39 | 2008 | 7 |
| 26 | Sham Shui Po | SSP | 114.14 | 22.34 | 11 | 2010 | 5 |
| 27 | New Tsing Yi Station | TY1 | 114.11 | 22.34 | 8 | 2010 | 5 |
| 28 | Tsuen Wan Shing Mun Valley | TW | 114.13 | 22.38 | 35 | 2010 | 5 |

Note: Dew point data of Sham Shui Po Station are all missing.

## 3.2 Storm Survey

The reliability of PMP estimates greatly depends on the availability and quality of hydrological and meteorological data as well as the depth and appropriateness of the analysis. Storm survey and investigation in a wider meteorological similarity region is needed by storm transposition method. In this regard, the storm survey and selection in the Southeast China including Zhejiang, Fujian, Guangdong, Guangxi, Hainan and Taiwan, is considered as an important step to the PMP estimation for Hong Kong.

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### 3.2.1 Methodology and Criteria for Storm Selection

Storms of tropical cyclones, extreme rainfall events induced by intense convection and trough of low-pressure storms in Hong Kong and its vicinity were considered in the selection exercise. The selection was made based on the considerations below:

(a) The ranking of storm in history in both severity and damage consequences in the target area; and

(b) The availability of hourly data for the life span of the storm (i.e. for two or more storms with the same severity level, the storm with no missing hourly data is preferred).

Moving window with fixed T-hour was used to determine the T-hour maximum rainfall over hourly observations, which were produced based on 1-min, 5-min and hourly rainfall observations.

The starting and ending hours of the storm centre were fixed to determine the T-hour area-average rainfall. This was to ensure that the rainfall observations encompassed by isohyets to make averaging were concurrent.

Assumption of continuity of rainfall over time and space was applied to data quality control wherever observations were unavailable, such as those in sea portion, when developing DAD curves.

Data verification - Any suspicious number including missing data was called for an original observation check. (Note: the original rainfall observations are kept by owners for most data purchase or acquisition due to restrictions to data management applied in Mainland China; however it is accessible to original records for check of suspicious data by owner at request for most cases.)

In some cases when 4-hour data and hourly observations were not available, for example, due to raingauge malfunction as a result of power outage or flooding, simple interpolation temporally such as between hours or a more reliable technique such as the inverse distance square method spatially were applied.

### 3.2.2 Results of Survey for Local Storms

The 1-min and 5-min raw data from 136 raingauge stations of GEO and HKO for the period between 1984 and 2015 were studied. Based on those data, the top fifteen storms for 4-hour rainfall were surveyed and listed in Table 3.5. Rainstorms in Hong Kong were mainly attributed to three types of weather system, namely tropical cyclone, trough of low pressure and Southwest Monsoon. Trough of low pressure was the most severe storm type; half of the top fifteen storms were caused by it.

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**Table 3.5 Top Fifteen 4-hour Rainfall Events in Hong Kong Based on Data of 136 HKO and GEO Raingauge Stations between 1984 and 2015**

| No. | ID | Date and Time (yy-mm-dd hh:mintue) | Storm type | 4-hour Maximum Rainfall (mm) |
|---|---|---|---|---|
| 1 | N19 | 2008-06-07 04:30 | Trough of low pressure | 384.0 |
| 2 | N14 | 1994-07-22 06:50 | Southwest Monsoon | 365.0 |
| 3 | R14 | 2000-08-24 01:35 | Super Typhoon (BILIS) | 358.5 |
| 4 | N28 | 2000-04-14 05:05 | Southwest Monsoon | 340.0 |
| 5 | N36 | 2003-05-05 02:25 | Trough of low pressure | 290.5 |
| 6 | R11 | 1993-11-05 01:25 | Severe Typhoon (IRA) | 285.5 |
| 7 | N47 | 2015-05-20 14:35 | Trough of low pressure | 285.0 |
| 8 | N47 | 2015-08-15 06:15 | Southwest Monsoon | 263.0 |
| 9 | N04 | 1997-06-04 04:50 | Trough of low pressure | 262.5 |
| 10 | N40 | 2010-07-22 14:55 | Typhoon (Chanthu) | 261.0 |
| 11 | H26 | 2014-05-11 23:00 | Trough of low pressure | 256.0 |
| 12 | N09 | 1997-07-02 04:30 | Trough of low pressure | 249.5 |
| 13 | N48 | 2015-10-07 06:05 | Northeast Monsoon | 246.0 |
| 14 | H10 | 1992-05-08 04:55 | Trough of low pressure | 243.0 |
| 15 | R11 | 2008-06-25 04:55 | Typhoon (Fenshen) | 236.5 |

These top fifteen 4-hour local storms were used for updating local DAD curves. Particularly, the local storm of 7 June 2008 with 4-hour maximum rainfall of 384 mm was considered as the most severe 4-hour storm in history of Hong Kong for comparison with the updated PMP estimates.

Also, based on the updated hourly data of the HKO HQ, a list of top ten 4-hour rainfalls recorded in HKO Headquarters between years 1885 and 2015 was identified and given in Table 3.6.

**Table 3.6 Top Ten 4-hour Rainfall Events in Hong Kong Based on Updated Hourly Data of HKO HQ between 1884 and 2015**

| No. | Date and Time (yy-mm-dd hh) | 4-hour Maximum Rainfall (mm) |
|---|---|---|
| 1 | 1889-05-30 02 | 302.3 |
| 2 | 1926-07-19 04 | 292.4 |
| 3 | 1966-06-12 06 | 273.4 |
| 4 | 2008-06-07 07 | 246.3 |
| 5 | 1886-07-15 14 | 241.6 |
| 6 | 1983-06-17 06 | 236.6 |
| 7 | 1923-10-30 24 | 213.0 |
| 8 | 1989-05-02 11 | 202.0 |
| 9 | 1925-07-17 06 | 196.0 |
| 10 | 1992-05-08 06 | 195.0 |

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### 3.2.3 Results of Survey for Non-local Storms in Southeast of Mainland China (Zhejiang, Fujian, Guangdong, Guangxi and Hainan Provinces)

One of the major challenges in this study is the acquisition of 4-hour rainfall data in Southeast China, including Zhejiang, Fujian, Guangdong, Guangxi and Hainan. Through extensive search and review of rainfall data, a total of 20 short duration rainfall events was selected as outstanding storms. The selected storms are tabulated in Appendix A. There were three rainfall records of No. 18 storm at Wenzhou station (one for 1-hour and two for 3-hour), because they were obtained from three different data sources.

### 3.2.4 Results of Survey for Non-local Storms in Macau

Based on the hourly data of Macau raingauge station, the top ten 4-hour rainfall in Macau between years 1952 and 2015 were identified and tabulated in Table 3.7.

**Table 3.7 Top Ten 4-hour Rainfall Events in Macau between 1952 and 2015**

| No. | Date and Time (yy-mm-dd hh) | 4-hour Maximum Rainfall (mm) |
|---|---|---|
| 1 | 1987-04-05 18 | 266.4 |
| 2 | 1982-05-29 04 | 244.4 |
| 3 | 2013-05-22 02 | 242.4 |
| 4 | 1996-07-26 19 | 239.8 |
| 5 | 1972-05-10 11 | 227.4 |
| 6 | 1982-08-18 06 | 215.8 |
| 7 | 1984-04-17 09 | 209.4 |
| 8 | 1966-06-12 14 | 203.5 |
| 9 | 1979-05-13 06 | 183.6 |
| 10 | 1986-05-11 14 | 160.4 |

### 3.2.5 Results of Survey for Non-local Storms in Taiwan

A list of top thirty 3-hour rainfall in Taiwan was obtained from the Central Weather Bureau (CWB) of Taiwan (龔楚媖 et al, 2012). The rainfall data were verified by checking the accuracy of each typhoon storm data from 1958 to 2014 based on the hourly data provided by CWB in January 2016. The top thirty 3-hour rainfalls with corrected data are given in Table 3.8 below.

The short duration rainstorms in Taiwan are mainly caused by typhoon and south-westerly flow. Based on the hourly data of typhoon storms from 1958 to 2014, a list of top ten 4-hour rainfall in Taiwan was determined by this Study and is given in Table 3.9. The locations of those rainfall are shown in Figure 3.4.

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**Table 3.8 List of Top Thirty 3-hour Rainfall Events in Taiwan between 1958 and 2014**

| No. | Name | Date | Storm | 3-hour Maximum Rainfall (mm) |
|---|---|---|---|---|
| 1 | Pengjiayu | 2002-07-10 | NAKRI | 476.0 |
| 2 | Suao | 2010-10-21 | MEGI | 444.0 |
| 3 | Jiaxian | 2008-07-17 | KALMAEGI | 389.0 |
| 4 | Guangfu | 2001-07-29 | TORAJI | 380.0 |
| 5 | Xinfa | 2008-07-17 | KALMAEGI | 368.5 |
| 6 | Tuchang | 2001-09-17 | NARI | 347.5 |
| 7 | Kaishan | 2008-07-17 | KALMAEGI | 347.0 |
| 8 | Tianxiang | 1997-08-29 | AMBER | 337.0 |
| 9 | Majia | 2010-09-19 | FANAPI | 335.5 |
| 10 | Zuoying | 2001-07-11 | TRAMI | 335.0 |
| 11 | Fenghuang | 2001-07-30 | TORAJI | 328.0 |
| 12 | Ahlishan | 2009-08-09 | MORAKOT | 325.5 |
| 13 | Penghu | 1974-07-06 | Southwesterly flow | 324.0 |
| 14 | Beiliao | 2008-07-17 | KALMAEGI | 324.0 |
| 15 | Gaoxiong | 1962-07-23 | KATE | 318.1 |
| 16 | Wangshan | 2010-09-19 | FANAPI | 316.5 |
| 17 | Gaozhong | 2008-07-17 | KALMAEGI | 315.0 |
| 18 | Buluowan | 1997-08-29 | AMBER | 312.0 |
| 19 | Sandimen | 2007-08-13 | Southwesterly flow | 312.0 |
| 20 | Ahlishan | 1996-07-31 | HERB | 311.5 |
| 21 | Tuchang | 2001-09-17 | NARI | 310.5 |
| 22 | Majia | 2007-08-13 | Southwesterly flow | 309.0 |
| 23 | Ahlishan | 1996-08-01 | Herb | 308.5 |
| 24 | Wangshan | 2010-09-19 | FANAPI | 308.5 |
| 25 | Ahlishan | 1996-08-01 | HERB | 308.5 |
| 26 | Matoushan | 2008-07-17 | KALMAEGI | 307.5 |
| 27 | Ahlishan | 2009-08-08 | MORAKOT | 305.0 |
| 28 | Majia | 2007-08-18 | SEPAT | 305.0 |
| 29 | Laiyi | 2009-08-08 | MORAKOT | 305.0 |
| 30 | Nanxi | 2008-7-17 | KALMAEGI | 300.5 |

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**Table 3.9 Updated Top Ten 4-hour Typhoon Storms in Taiwan between 1958 and 2014**

| No. | Name | Date and Time (yy-mm-dd hh) | Storm | 4-hour Maximum Rainfall (mm) |
|---|---|---|---|---|
| 1 | Suao | 2010-10-21 12 | MEGI | 558.5 |
| 2 | Pengjiayu | 2002-07-10 12 | NAKRI | 556.0 |
| 3 | Jiaxian | 2008-07-17 21 | KALMAEGI | 496.0 |
| 4 | Majia | 2010-09-19 13 | FANAPI | 435.5 |
| 5 | Hengchun | 2012-08-24 06 | TEMBIN | 435.5 |
| 6 | Tuchang | 2001-09-17 21 | NARI | 432.5 |
| 7 | Tianxiang | 1997-08-29 08 | AMBER | 419.5 |
| 8 | Ahlishan | 1996-08-01 01 | HERB | 415.5 |
| 9 | Ahlishan | 2009-08-08 24 | MORAKOT | 404.5 |
| 10 | Bailan | 2013-07-13 03 | SOULIK | 400.5 |

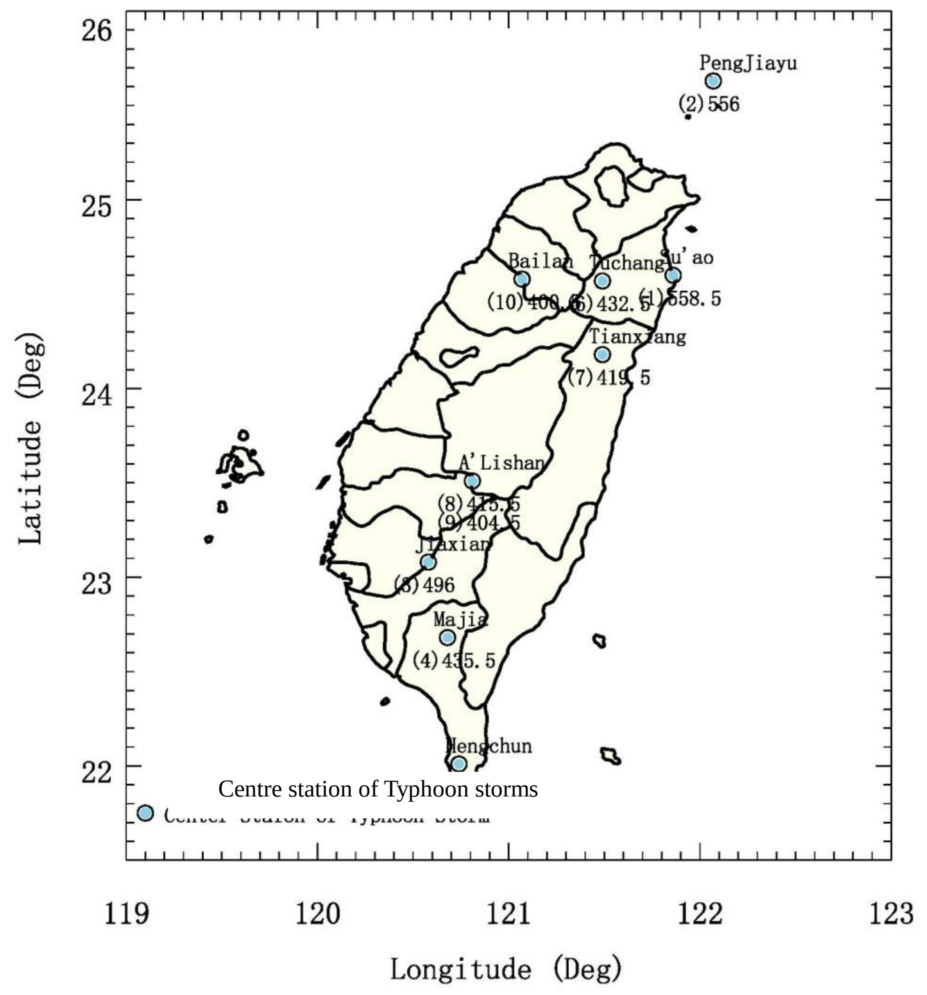


**Figure 3.4 Locations of the Storm Centre of Top Ten 4-hour Rainfall Events in Taiwan**

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The typhoon Kalmaegi was considered as a candidate of target storms to be used for storm transposition analysis on account of its high ranking in severity, track, the moisture flux in the typhoon-prone NW Pacific area, and the availability of rainfall data. Besides, typhoon storms Kalmaegi, Herb, Morakot and Fanapi, having similar track and moisture flux, were the candidates for working out a generalised pattern of convergence component for transposition. The detailed introduction of storm analysis is given in Section 5.2.

# 4 Statistical Estimates of 4-hour PMP in Hong Kong

## 4.1 Data Adopted for Statistical Analysis

The historical rainfall data for Hong Kong included a total of 136 raingauge stations. However, the length of time period of only 76 raingauge stations (45 from GEO and 31 from HKO) are 17 years[a] or more. These raingauge stations were selected for statistical estimate. The geographic locations of all these 76 raingauge stations are shown in Figure 4.1.

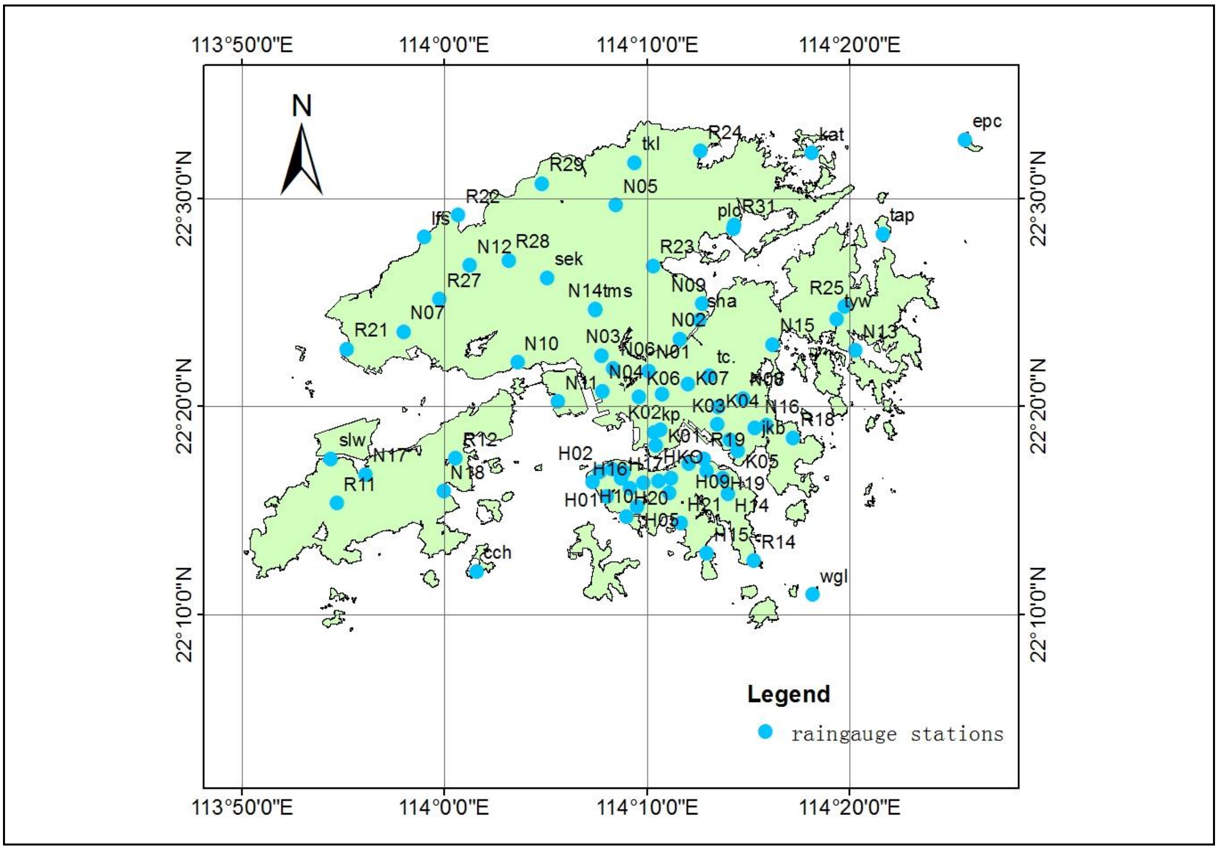


**Figure 4.1 Locations of 76 Raingauge Stations in Hong Kong with Hourly Rainfall Data Observation Periods Longer than 17 Years**

[a] The minimum of data observation period was reduced from 27 years down to 17 years was agreed by experts of the 4-hour PMP Updating Study Working Group in a progress meeting in late May 2016. There is no major difference between the two minimum data observation period as most stations with short years overlooked in the statistical approach. From statistical points of view, a group of stations with data length of 30 or longer years is more appropriate because the Normal Distribution used for error analysis is good for data length of 30 years or more while the Student's t-distribution model is applicable for data length less than 30 years.

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## 4.2 Results of 4-hour PMP Estimate in Hong Kong by Statistical Method

Criteria and procedures applied to screening of data for statistical analysis (see Section 2.1) are described in items (a) to (e) below:

(a) Sort the data in descending order based on the maximum value, $X_m$;

(b) Select the top ten raingauge stations into the computation process for the study area;

(c) Check the required stable size $N_s$ and then discard the raingauge stations that did not meet the screening criteria started in Section 1.3.1 of AECOM and Lin (2015); and

(d) Calculate the 4-hour PMP according to the shortlisted rainfall measurement (see Section 1.3.1 of AECOM and Lin, 2015).

The 4-hour PMP estimate in Hong Kong based on statistical analysis is 559.3 mm. Details of the computation are given in Appendix B.

# 5 Storm Separation

Based on storm survey, two major storms were selected for storm separation analysis as the potential candidates to be used for storm transposition. They are the 9 October 1999 Storm centred at Xiazhanglong (下張隆) in Fujian Province specified as #9914 Typhoon in Appendix A, and the severe Typhoon Kalmaegi of 17 July 2008 centred at Ahlishan (阿里山) in Taiwan.

## 5.1 Storm Separation of 9 October 1999 Storm in Fujian

### 5.1.1 Data

(1) Rainfall data

Rainfall data of a total of 50 raingauge stations of 9 October 1999 Storm in Fujian Province were provided by Fujian Hydrological Bureau. Details of the longitude, latitude and data type of each station are given in Table 5.1.

**Table 5.1 Data Information of Fifty Raingauge Stations of 9 October 1999 Storm in Fujian (Sheet 1 of 2)**

| No. | Name | Longitude | Latitude | Data Type |
|---|---|---|---|---|
| 1 | 赤水 Chishui | 118.13 | 25.65 | 1-hour |
| 2 | 格頭 Getou | 118.18 | 25.57 | 1-hour |
| 3 | 蓋德 Gaide | 118.18 | 25.52 | 1-hour |
| 4 | 英山 Yingshan | 118.20 | 25.47 | 1-hour |
| 5 | 鳳洋 Fengyang | 118.28 | 25.50 | 1-hour |
| 6 | 長慶 Changqing | 118.58 | 25.88 | 1-hour |
| 7 | 遊洋 Youyang | 118.82 | 25.62 | 1-hour |
| 8 | 梧桐 Wutong | 118.75 | 25.73 | 1-hour |
| 9 | 白雲 Baiyun | 118.90 | 26.03 | 1-hour |
| 10 | 北山 Beishan | 118.95 | 26.02 | 1-hour |
| 11 | 漁溪 Yuxi | 118.90 | 25.95 | 1-hour |
| 12 | 太平口 Taipingkou | 118.93 | 25.88 | 1-hour |
| 13 | 永泰 (清水壑)<br>Yongtai (Qingshuihe) | 118.95 | 25.87 | 1-hour |
| 14 | 仙榮 Xianrong | 117.90 | 25.37 | 1-hour |
| 15 | 坑仔口 Kengzaikou | 118.02 | 25.42 | 1-hour |
| 16 | 官嶺 Guanling | 118.13 | 25.25 | 1-hour |
| 17 | 鳳巢 Fengchao | 118.27 | 24.85 | 1-hour |
| 18 | 錦溪 Jinxi | 118.10 | 25.43 | 1-hour |
| 19 | 外碧 Waibi | 118.40 | 25.30 | 1-hour |
| 20 | 泉州大橋 Quanzhoudaqiao | 118.58 | 24.90 | 1-hour |
| 21 | 磁灶 Cizao | 118.48 | 24.83 | 1-hour |
| 22 | 吉宦 Jihuan | 118.97 | 25.68 | 1-hour |
| 23 | 白沙 Baisha | 119.00 | 25.60 | 1-hour |
| 24 | 西墘 Xiqian | 118.58 | 25.53 | 1-hour |
| 25 | 仙遊 Xianyou | 118.68 | 25.37 | 1-hour |
| 26 | 周宅 Zhouzhai | 118.73 | 25.28 | 1-hour |
| 27 | 汾山 Fenshan | 118.70 | 25.52 | 1-hour |
| 28 | 社硎 Shexing | 118.62 | 25.50 | 1-hour |
| 29 | 石馬 Shima | 118.78 | 25.37 | 1-hour |

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**Table 5.1 Data Information of Fifty Raingauge Stations of 9 October 1999 Storm in Fujian (Sheet 2 of 2)**

| No. | Name | Longitude | Latitude | Data Type |
|---|---|---|---|---|
| 30 | 瀨溪 Laixi | 118.93 | 25.38 | 1-hour |
| 31 | 莆田 Putian | 119.02 | 25.43 | 1-hour |
| 32 | 後嶺 Houling | 118.83 | 25.53 | 1-hour |
| 33 | 九鯉湖 Jiulihu | 118.82 | 25.47 | 1-hour |
| 34 | 白硎 Baixing | 118.95 | 25.55 | 1-hour |
| 35 | 東圳水庫 Dongzhenshuiku | 118.98 | 25.48 | 1-hour |
| 36 | 忠門 Zhongmen | 119.08 | 25.20 | 1-hour |
| 37 | 惠安 Huian | 118.80 | 25.03 | 1-hour |
| 38 | 崇武 Chongwu | 118.93 | 24.88 | 1-hour |
| 39 | 東園 Dongyuan | 118.75 | 24.92 | 1-hour |
| 40 | 赤湖 Chihu | 118.70 | 24.77 | 1-hour |
| 41 | 英林 Yinglin | 118.58 | 24.63 | 1-hour |
| 42 | 橋頭 Qiaotou | 118.80 | 25.57 | 15-min |
| 43 | 下張隆 Xiazhanglong | 118.85 | 25.57 | 15-min |
| 44 | 林兜 Lindou | 118.85 | 25.55 | 15-min |
| 45 | 渡裡 Duli | 118.88 | 25.52 | 15-min |
| 46 | 火燒院 Huoshaoyuan | 118.48 | 25.40 | 10-min |
| 47 | 白鴿嶺 Baigeling | 118.48 | 25.38 | 10-min |
| 48 | 內洋 Neiyang | 118.50 | 25.38 | 10-min |
| 49 | 佛堂 Fotang | 118.52 | 25.38 | 10-min |
| 50 | 溪口 Xikou | 118.53 | 25.38 | 10-min |

(2) Historical annual maximum series rainfall data

Annual maximum rainfall series of different durations (1 hour, 3 hour and 6 hour) of 217 raingauge stations in Fujian Province were provided by Fujian Hydrological Bureau. Figure 5.1 shows the locations of the raingauge stations.

(3) 2.5° × 2.5° reanalysis data

2.5° × 2.5° reanalysis data of 8-10 October 1999 were downloaded from the National Centers for Environmental Prediction (NCEP) of the United States.

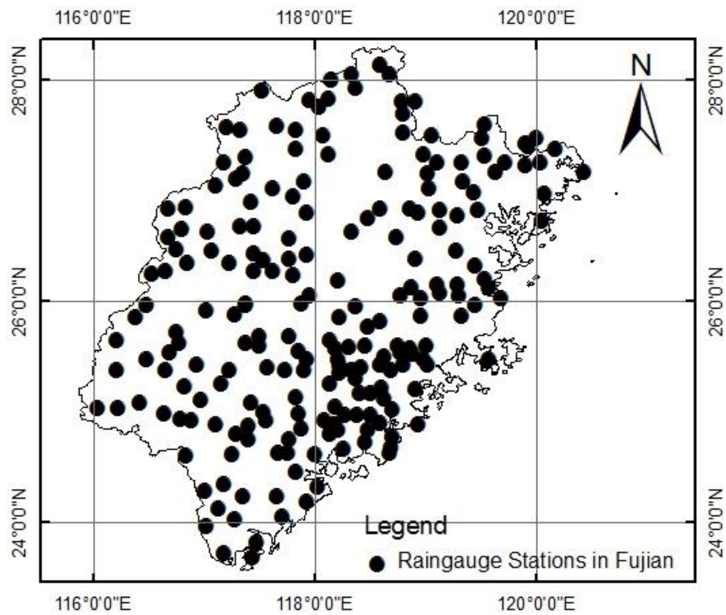


**Figure 5.1 Locations of Raingauge Stations in Fujian**

### 5.1.2 Isohyet Map of 4-hour Maximum Rainfall of 9 October 1999 Storm

The Isohyet map of 4-hour maximum rainfall of 9 October 1999 storm is shown in Figure 5.2.

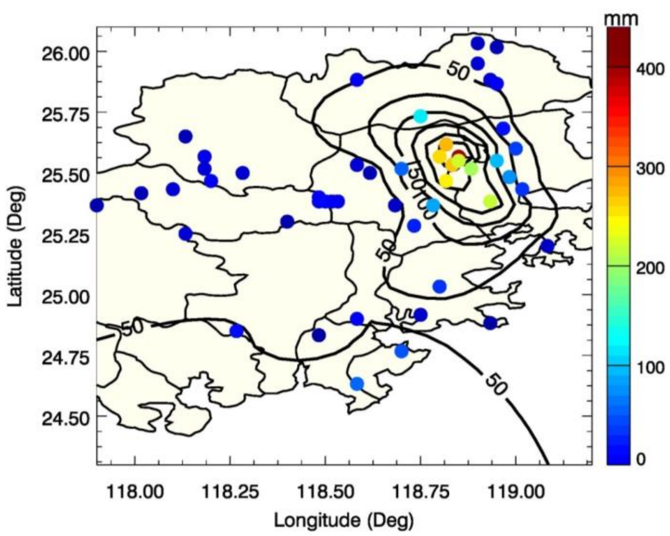


**Figure 5.2 4-hour Maximum Isohyet Map of 9 October 1999 Storm**

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### 5.1.3 Moisture Flux during Storm Period

The time of the 4-hour maximum rainfall of the storm started at 5 pm, 9 October 1999. Accordingly, the moisture flux at 08Z and 14Z on 9 October 1999 is shown in Figures 5.3 and 5.4 respectively. There existed a consistently strong southeast in general flow flux with respect to the storm center.

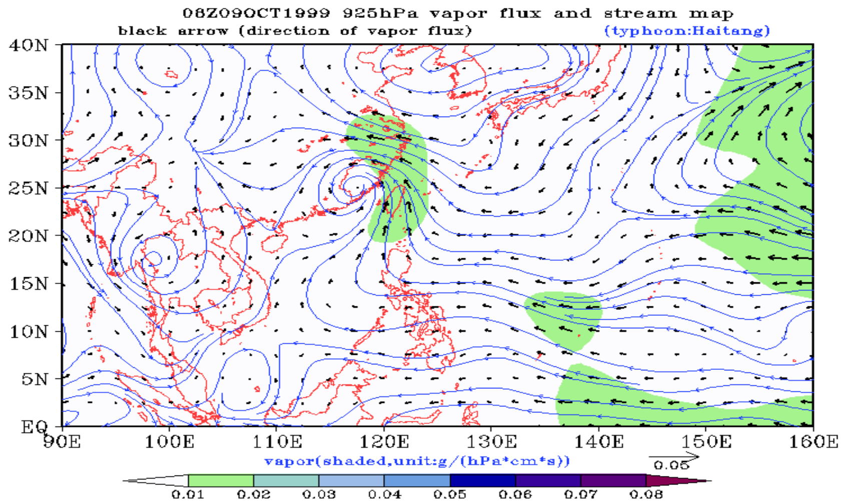


**Figure 5.3 Moisture Flux at 08Z in 9 Oct 1999**

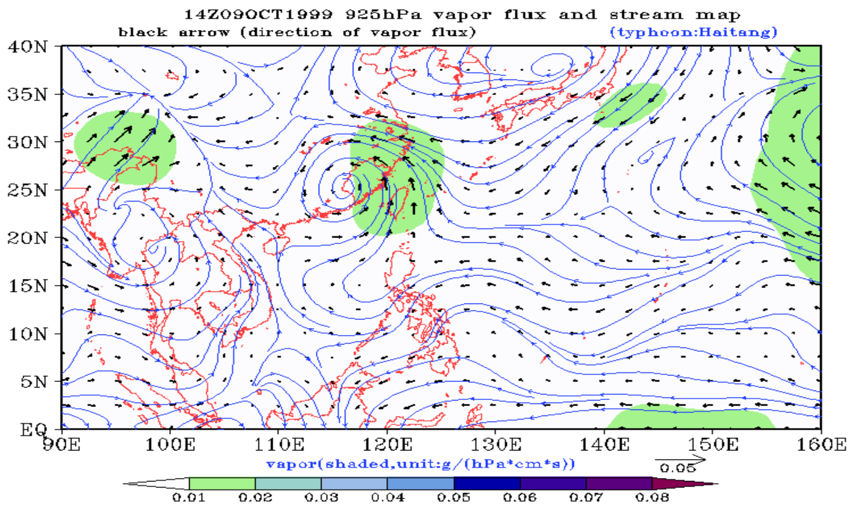


**Figure 5.4 Moisture Flux at 14Z in 9 Oct 1999**

### 5.1.4 Elevation Map of the Raingauge Stations in Fujian Province

The elevation map of the raingauge stations in Fujian is shown in Figure 5.5.

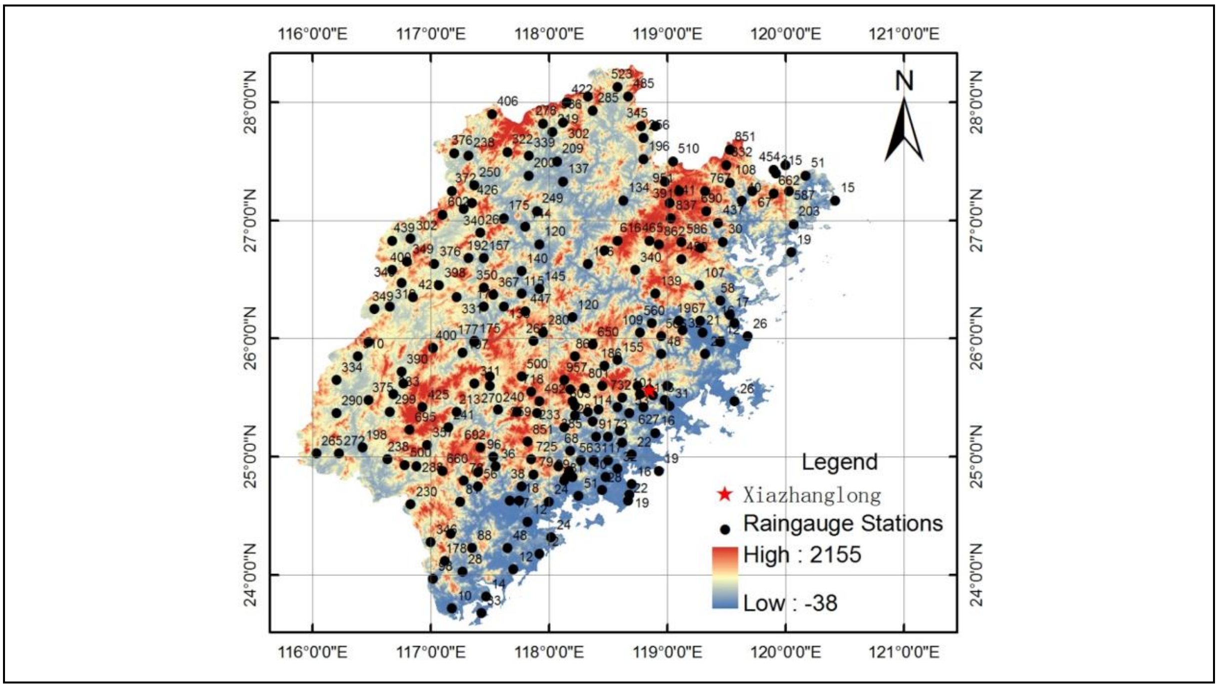


**Figure 5.5   Elevation Map of the Raingauge Stations in Fujian Province**

### 5.1.5   Raingauge Stations Selected for SDOIF Analysis

Combing the moisture flux, isohyets map of the storm and the available historical annual rainfall series, 51 raingauge stations were selected for SDOIF analysis. Those raingauge stations are shown in Figure 5.6. A total of four raingauge stations were selected as the base stations without orographic influence. They were Shenhu (深滬, 2), Yongning (永寧, 4), Chihu (赤湖, 6) and Chongwu (崇武, 13), indicated by the red rectangles shown in Figure 5.6.

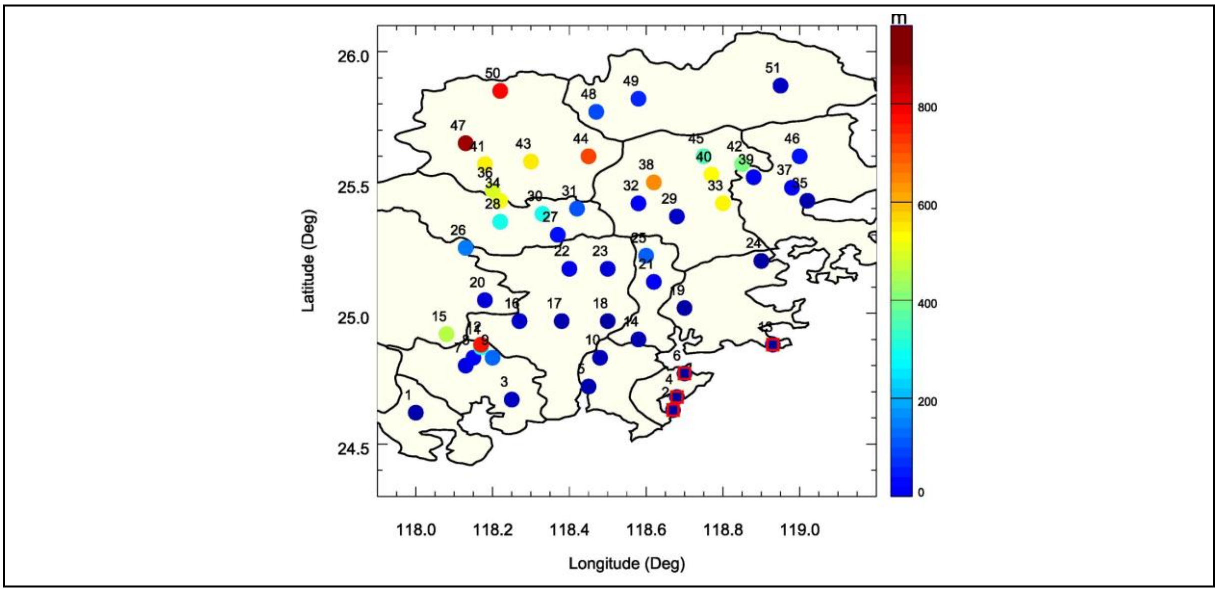


**Figure 5.6   Locations of Raingauge Stations Chosen for SDOIF Analysis**

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### 5.1.6 4-hour Mean Annual Maximum Rainfall for Each Raingauge Station

The mean annual maximum rainfall of different durations (1-hour, 3-hour and 6-hour) of the 51 raingauge stations in the targeted area are shown in Table 5.2.

**Table 5.2 Mean Annual Maximum Rainfalls of Different Durations of Raingauge Stations in Fujian (Sheet 1 of 2)**

| No. | Longitude | Latitude | Elevation (m) | Mean Annual Maximum Rainfall (mm) | | |
|---|---|---|---|---|---|---|
| | | | | 1-hour | 3-hour | 6-hour |
| 1 | 118.00 | 24.62 | 24 | 44.81 | 72.28 | 92.44 |
| 2 | 118.67 | 24.63 | 22 | 41.94 | 71.09 | 95.79 |
| 3 | 118.25 | 24.67 | 51 | 43.92 | 69.47 | 92.64 |
| 4 | 118.68 | 24.68 | 19 | 40.67 | 69.54 | 91.39 |
| 5 | 118.45 | 24.72 | 28 | 44.23 | 70.06 | 93.86 |
| 6 | 118.70 | 24.77 | 16 | 42.8 | 72.37 | 91.78 |
| 7 | 118.13 | 24.80 | 81 | 53.53 | 81.13 | 100.81 |
| 8 | 118.15 | 24.83 | 99 | 54.52 | 82.7 | 104.7 |
| 9 | 118.20 | 24.83 | 214 | 55.46 | 89.93 | 120.82 |
| 10 | 118.48 | 24.83 | 40 | 47.18 | 77.86 | 104.53 |
| 11 | 118.17 | 24.87 | 366 | 55.25 | 88.77 | 113.89 |
| 12 | 118.17 | 24.88 | 848 | 57.36 | 92.91 | 124.34 |
| 13 | 118.93 | 24.88 | 19 | 44.04 | 69.14 | 87.33 |
| 14 | 118.58 | 24.90 | 32 | 45.72 | 68.4 | 88.53 |
| 15 | 118.08 | 24.92 | 551 | 44.06 | 76.87 | 100.57 |
| 16 | 118.27 | 24.97 | 56 | 44.75 | 68.35 | 90.02 |
| 17 | 118.38 | 24.97 | 31 | 46.35 | 67.47 | 87.45 |
| 18 | 118.50 | 24.97 | 17 | 49.58 | 72.58 | 89.46 |
| 19 | 118.70 | 25.02 | 22 | 40.85 | 65.48 | 82.69 |
| 20 | 118.18 | 25.05 | 68 | 50.05 | 68 | 85.77 |
| 21 | 118.62 | 25.12 | 101 | 47.54 | 64.6 | 85.4 |
| 22 | 118.40 | 25.17 | 91 | 43.95 | 65.7 | 82.89 |
| 23 | 118.50 | 25.17 | 73 | 43.81 | 61.96 | 76.89 |
| 24 | 118.90 | 25.20 | 16 | 49.69 | 69.21 | 88.27 |
| 25 | 118.60 | 25.22 | 205 | 43.31 | 66.02 | 90.1 |
| 26 | 118.13 | 25.25 | 233 | 47.43 | 67.81 | 81.97 |

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**Table 5.2 Mean Annual Maximum Rainfalls of Different Durations of Raingauge Stations in Fujian (Sheet 2 of 2)**

| No. | Longitude | Latitude | Elevation (m) | Mean Annual Maximum Rainfall (mm) | | |
|---|---|---|---|---|---|---|
| | | | | 1-hour | 3-hour | 6-hour |
| 27 | 118.37 | 25.30 | 128 | 34.7 | 67.07 | 87.9 |
| 28 | 118.22 | 25.35 | 384 | 37.93 | 63.82 | 86.34 |
| 29 | 118.68 | 25.37 | 53 | 44.64 | 68.53 | 84.03 |
| 30 | 118.33 | 25.38 | 385 | 37.25 | 60.69 | 80.44 |
| 31 | 118.42 | 25.40 | 192 | 48.42 | 70.69 | 85.33 |
| 32 | 118.58 | 25.42 | 114 | 45.4 | 63.94 | 76.77 |
| 33 | 118.80 | 25.42 | 627 | 51.61 | 76.6 | 102.97 |
| 34 | 118.22 | 25.43 | 603 | 45.57 | 69.3 | 86.37 |
| 35 | 119.02 | 25.43 | 31 | 41.63 | 67.44 | 86.9 |
| 36 | 118.20 | 25.47 | 580 | 45.93 | 69.26 | 85.69 |
| 37 | 118.98 | 25.48 | 113 | 48.31 | 76.61 | 97.72 |
| 38 | 118.62 | 25.5 | 732 | 48.59 | 72.22 | 94.49 |
| 39 | 118.88 | 25.52 | 101 | 50.96 | 78.07 | 98.61 |
| 40 | 118.77 | 25.53 | 618 | 45.79 | 72.09 | 101.64 |
| 41 | 118.18 | 25.57 | 631 | 44.46 | 63.46 | 78.88 |
| 42 | 118.85 | 25.57 | 491 | 48.73 | 78.13 | 102.62 |
| 43 | 118.3 | 25.58 | 637 | 40.63 | 60.77 | 75.2 |
| 44 | 118.45 | 25.6 | 801 | 43.88 | 61.57 | 87.39 |
| 45 | 118.75 | 25.6 | 438 | 49.98 | 60.74 | 76.61 |
| 46 | 119 | 25.6 | 134 | 46.83 | 75.53 | 95.73 |
| 47 | 118.13 | 25.65 | 957 | 41.21 | 60.08 | 74.49 |
| 48 | 118.47 | 25.77 | 186 | 40.2 | 59.63 | 73.8 |
| 49 | 118.58 | 25.82 | 155 | 38.55 | 56.45 | 71.13 |
| 50 | 118.22 | 25.85 | 867 | 41 | 49.98 | 68.72 |
| 51 | 118.95 | 25.87 | 48 | 44.36 | 62.7 | 79.81 |

The 4-hour mean annual maximum rainfall for each station was obtained by interpolation. Either the linear fitting or logarithmic curve fitting was utilised to establish the trend based on the available 1-hour, 3-hour and 6-hour mean annual maximum rainfalls. For each raingauge station, logarithmic regression was adopted if the sum of squared residual (i.e. R value) is smaller than by using linear regression, and vice versa. Following the regression analysis, the estimated 4-hour mean annual maximum rainfalls for each raingauge station are given in Table 5.3.

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**Table 5.3 4-hour Mean Annual Maximum Rainfalls of Raingauge Stations in Fujian (Sheet 1 of 2)**

| No. | Name | Longitude | Latitude | Elevation (m) | Estimated 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|
| 1 | 三社 Sanshe | 118.00 | 24.62 | 24 | 81.02 |
| 2 | 深滬 Shenhu | 118.67 | 24.63 | 22 | 82.18 |
| 3 | 馬巷 Maxiang | 118.25 | 24.67 | 51 | 80.02 |
| 4 | 永寧 Yongning | 118.68 | 24.68 | 19 | 79.09 |
| 5 | 安海 Anhai | 118.45 | 24.72 | 28 | 80.93 |
| 6 | 赤湖 Chihu | 118.70 | 24.77 | 16 | 80.53 |
| 7 | 汀溪水庫 Tingxishuiku | 118.13 | 24.80 | 81 | 89.60 |
| 8 | 五豐 Wufeng | 118.15 | 24.83 | 99 | 92.39 |
| 9 | 造水(三甲)<br>Zaoshui (Sanjia) | 118.20 | 24.83 | 214 | 103.97 |
| 10 | 磁灶 Cizao | 118.48 | 24.83 | 40 | 89.90 |
| 11 | 汪前 Wangqian | 118.17 | 24.87 | 366 | 99.72 |
| 12 | 荇後 Xinghou | 118.17 | 24.88 | 848 | 107.15 |
| 13 | 崇武 Chongwu | 118.93 | 24.88 | 19 | 77.00 |
| 14 | 泉州大橋 Quanzhoudaqiao | 118.58 | 24.90 | 32 | 77.53 |
| 15 | 村內 Cunnei | 118.08 | 24.92 | 551 | 87.11 |
| 16 | 英都 Yingdu | 118.27 | 24.97 | 56 | 78.25 |
| 17 | 南安 Nanan | 118.38 | 24.97 | 31 | 76.65 |
| 18 | 石礱 Shilong | 118.50 | 24.97 | 17 | 79.90 |
| 19 | 黃塘 Huangtang | 118.70 | 25.02 | 22 | 72.84 |
| 20 | 安溪 Anxi | 118.18 | 25.05 | 68 | 72.64 |
| 21 | 馬甲 Majia | 118.62 | 25.12 | 101 | 70.86 |
| 22 | 山美水庫 Shanmeishuiku | 118.40 | 25.17 | 91 | 73.30 |
| 23 | 羅中 Luozhong | 118.50 | 25.17 | 73 | 68.62 |
| 24 | 南埔 Nanpu | 118.90 | 25.20 | 16 | 74.13 |
| 25 | 西頭埔 Xitoupu | 118.60 | 25.22 | 205 | 72.65 |
| 26 | 官嶺 Guanling | 118.13 | 25.25 | 233 | 73.86 |
| 27 | 東關 Dongguan | 118.37 | 25.30 | 128 | 75.77 |

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**Table 5.3 4-hour Mean Annual Maximum Rainfalls of Raingauge Stations in Fujian (Sheet 2 of 2)**

| No. | Name | Longitude | Latitude | Elevation (m) | Estimated 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|
| 28 | 大卿 Daqing | 118.22 | 25.35 | 384 | 73.99 |
| 29 | 仙遊 Xianyou | 118.68 | 25.37 | 53 | 75.02 |
| 30 | 洋上 Yangshang | 118.33 | 25.38 | 385 | 69.55 |
| 31 | 湖洋 Huyang | 118.42 | 25.40 | 192 | 76.84 |
| 32 | 度尾 Duwei | 118.58 | 25.42 | 114 | 69.41 |
| 33 | 東宮 Donggong | 118.80 | 25.42 | 627 | 83.83 |
| 34 | 嵩山 Songshan | 118.22 | 25.43 | 603 | 76.66 |
| 35 | 莆田 Putian | 119.02 | 25.43 | 31 | 75.94 |
| 36 | 英山 Yingshan | 118.20 | 25.47 | 580 | 76.31 |
| 37 | 東圳水庫 Dongzhenshuiku | 118.98 | 25.48 | 113 | 85.80 |
| 38 | 社硎 Shexing | 118.62 | 25.50 | 732 | 77.79 |
| 39 | 渡裡 Duli | 118.88 | 25.52 | 101 | 87.05 |
| 40 | 石牌 Shipai | 118.77 | 25.53 | 618 | 80.55 |
| 41 | 格頭 Getou | 118.18 | 25.57 | 631 | 70.32 |
| 42 | 下張隆 Xiazhanglong | 118.85 | 25.57 | 491 | 89.08 |
| 43 | 雷峰 Leifeng | 118.30 | 25.58 | 637 | 66.99 |
| 44 | 棗坑 Zaokeng | 118.45 | 25.60 | 801 | 70.08 |
| 45 | 下社 Xiashe | 118.75 | 25.60 | 438 | 65.99 |
| 46 | 白沙 Baisha | 119.00 | 25.60 | 134 | 84.19 |
| 47 | 赤水 Chishui | 118.13 | 25.65 | 957 | 66.39 |
| 48 | 洑口 Fukou | 118.47 | 25.77 | 186 | 65.77 |
| 49 | 嵩口 Songkou | 118.58 | 25.82 | 155 | 62.99 |
| 50 | 葛坑 Gekeng | 118.22 | 25.85 | 867 | 56.97 |
| 51 | 永泰(清水壑) Yongtai (Qingshuihe) | 118.95 | 25.87 | 48 | 66.94 |

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### 5.1.7 Development of OIF for the Target Area

A gridded calculation frame was set up to cover the whole Fujian area. Figure 5.7 shows the spatial distribution of the 4-hour OIF for Fujian at a resolution of 5 km × 5 km.

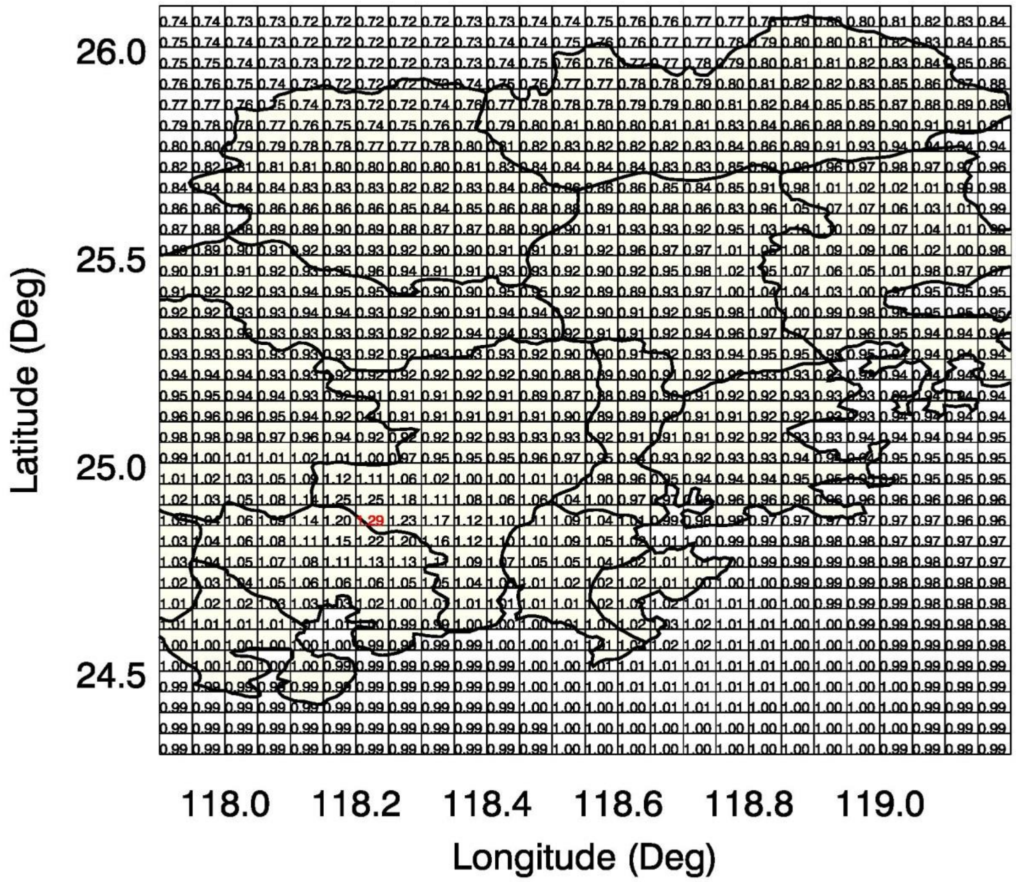


**Figure 5.7 4-hour OIF for Targeted Area at a Resolution of 5 km × 5 km**

### 5.1.8 Convergence Component of the 9 October 1999 Storm

The SDOIF method was applied to decouple the 9 October 1999 storm rainfall into two components, namely the convergence component and the orographic component. Figure 5.8 shows the grid map of 4-hour convergence component of the 9 October 1999 storm. The maximum convergence rainfall is 359.3 mm.

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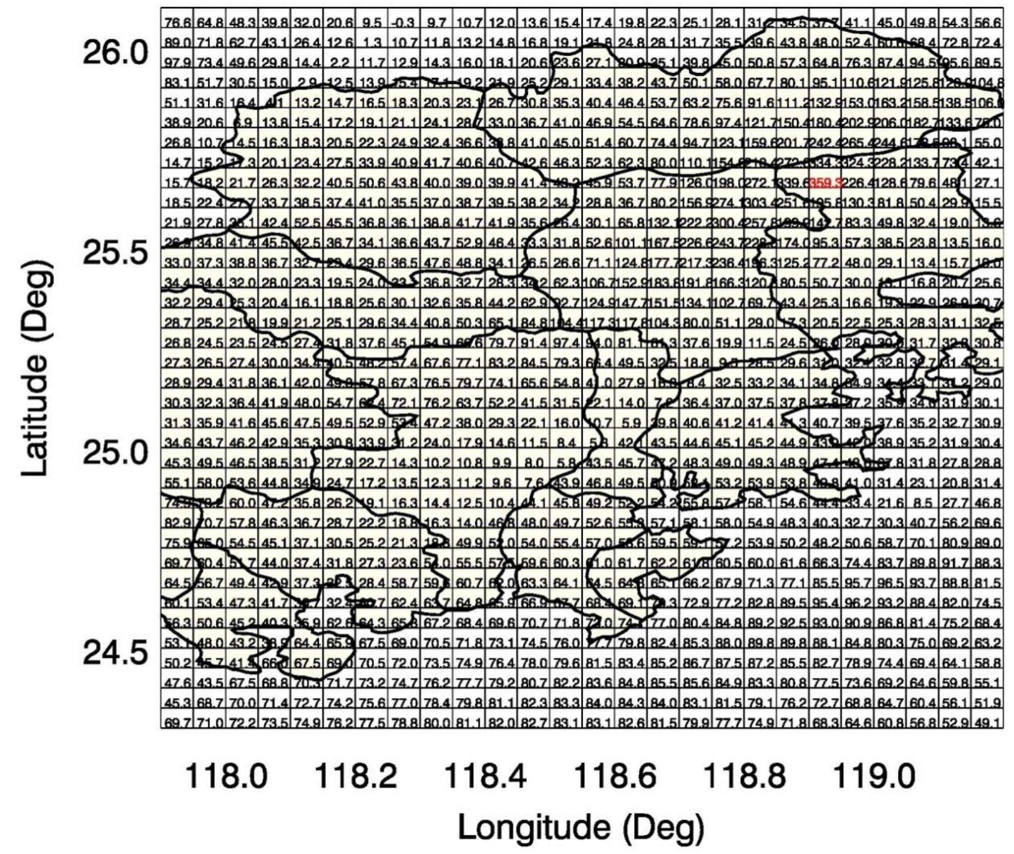


**Figure 5.8 4-hour Gridded Convergence Component of 9 October 1999 Storm**

## 5.2 Storm Separation of Storms in Taiwan

Based on the typhoon path analysis, the severity as well as the damage evaluation, the Megi of 21 October 2010 (no. 1 in Table 3.9) and the Nakri of 10 July 2002 (no. 2 in Table 3.9) were deemed to be irrelevant to the storm transposition for PMP study in Hong Kong. The Kalmaegi ("海鷗" in Chinese) of 17 July 2008 (no. 3 in Table 3.9) was thus selected. Furthermore, a synoptic analysis revealed that the scenario of a strong moisture flux of SW hitting the center of Ahlishan mountain for the Kalmaegi storm was very similar to the case of Typhoon Morakot ("莫拉克") that slashed Taiwan on 8 August 2009 and poured down a record rainfall of 1,583 mm-24-hour at the centre. However, the rainfall amounts of short duration of Morakot were not remarkable enough to be considered for transposition, with 404.5 mm-4-hour observed. Therefore, Kalmaegi storm was chosen as the target storm for storm transposition.

### 5.2.1 Data

(1) Rainfall data:
Hourly data of typhoon Kalmaegi, Herb, Morakot and Fanapi, which were provided by Central Weather Bureau (CWB) of Taiwan.

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(2) 2.5° × 2.5° reanalysis data:
2.5° × 2.5° reanalysis data were downloaded from National Centers for Environmental Prediction (NCEP) of the United States.

(3) Typhoon track:
Typhoon track data of typhoon Kalmaegi, Herb, Morakot and Fanapi were provided by the CWB of Taiwan.

(4) Historical annual maximum rainfall data:
4-hour annual maximum rainfall for 66 raingauge stations in Taiwan. Figure 3.1 shows the geographic locations of the raingauge stations. The 4-hour mean annual maximum rainfalls for each station are given in Table 5.4.

**Table 5.4 4-hour Mean Annual Maximum Rainfalls in Taiwan (Sheet 1 of 3)**

| | No. | Name | Longitude | Latitude | Elevation (m) | N-years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|---|
| WRA | 1 | 雙崎(2) Shuangqi(2) | 120.91 | 24.29 | 543 | 45 | 137.08 |
| | 2 | 龍神橋 Longshenqiao | 120.87 | 23.78 | 322 | 44 | 132.66 |
| | 3 | 集集(2) Jiji(2) | 120.78 | 23.83 | 9 | 50 | 132.29 |
| | 4 | 北港(2) Beigang(2) | 120.30 | 23.58 | 215 | 49 | 114.54 |
| | 5 | 旗山(4) Qishan(4) | 120.48 | 22.88 | 64 | 45 | 128.23 |
| | 6 | 屏東(5) Pingdong(5) | 120.47 | 22.65 | 25 | 48 | 138.9 |
| | 7 | 鹿鳴橋 Lumingqiao | 121.09 | 22.90 | 190 | 43 | 120.54 |
| | 8 | 林口(1) Linkou(1) | 121.38 | 25.08 | 250 | 35 | 96.97 |
| | 9 | 火燒寮 Huoshaoliao | 121.75 | 24.98 | 380 | 50 | 136.99 |
| | 10 | 福山(3) Fushan(3) | 121.50 | 24.78 | 500 | 35 | 143.43 |
| | 11 | 太閣南 Taigenan | 121.15 | 24.63 | 940 | 48 | 125.28 |
| | 12 | 橫龍山 Henglongshan | 120.97 | 24.47 | 550 | 43 | 146.53 |
| | 13 | 大坪頂 Dapingding | 120.73 | 24.43 | 190 | 33 | 115.12 |
| | 14 | 八仙山(1) Baxianshan(1) | 121.00 | 24.13 | 1600 | 23 | 146.17 |
| | 15 | 雪嶺 Xueling | 121.03 | 24.28 | 2575 | 42 | 126.77 |
| | 16 | 頭汴坑 Toubiankeng | 120.81 | 24.12 | 480 | 44 | 143.39 |
| | 17 | 萬興(2) Wanxing(2) | 120.42 | 23.96 | 11 | 44 | 103.58 |
| | 18 | 翠峰 Cuifeng | 121.20 | 24.11 | 2303 | 44 | 97.17 |


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**Table 5.4 4-hour Mean Annual Maximum Rainfalls in Taiwan (Sheet 2 of 3)**

| | No. | Name | Longitude | Latitude | Elevation (m) | N-years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|---|
| WRA | 19 | 望鄉 Wangxiang | 120.93 | 23.62 | 2200 | 46 | 128.24 |
| | 20 | 卡奈托灣(2) Kanaituowan(2) | 121.09 | 23.75 | 1390 | 31 | 91.81 |
| | 21 | 西巒 Xiluan | 120.92 | 23.71 | 1666 | 45 | 117.9 |
| | 22 | 六分寮 Liufenliao | 120.64 | 23.93 | 427 | 43 | 126.18 |
| | 23 | 北山(2) Beishan(2) | 120.89 | 23.99 | 339 | 44 | 121.17 |
| | 24 | 西螺(2) Xiluo(2) | 120.47 | 23.80 | 30 | 42 | 108.94 |
| | 25 | 林內(1) Linnei(1) | 120.61 | 23.76 | 82 | 42 | 118.71 |
| | 26 | 大埔 Daupu | 120.62 | 23.63 | 205 | 42 | 138.93 |
| | 27 | 褒忠(2) Baozhong(2) | 120.31 | 23.70 | 13 | 42 | 103.83 |
| | 28 | 大湖山 Dauhushan | 120.62 | 23.48 | 725 | 46 | 177.38 |
| | 29 | 樟腦寮(2) Zhangnaoliao(2) | 120.60 | 23.53 | 545 | 44 | 172.85 |
| | 30 | 中坑(3) Zhongkeng(3) | 120.52 | 23.57 | 95 | 45 | 133.62 |
| | 31 | 關子嶺(2) Guanziling(2) | 120.51 | 23.33 | 350 | 43 | 153.96 |
| | 32 | 木柵 Mushan | 120.47 | 22.98 | 78 | 44 | 140.98 |
| | 33 | 阿蓮(2) Ahlian(2) | 120.33 | 22.88 | 21 | 40 | 140.87 |
| | 34 | 甲仙(2) Jiaxian(2) | 120.59 | 23.08 | 355 | 47 | 147.15 |
| | 35 | 新豐 Xinfeng | 120.65 | 22.88 | 166 | 38 | 140.37 |
| | 36 | 泰武(1) Taiwu(1) | 120.70 | 22.61 | 950 | 44 | 239.71 |
| | 37 | 南和 Nanhe | 120.64 | 22.43 | 140 | 45 | 150.98 |
| | 38 | 阿禮 Ahli | 120.76 | 22.73 | 1158 | 45 | 194.84 |
| | 39 | 三地門 Sandimen | 120.65 | 22.71 | 150 | 44 | 165.82 |
| | 40 | 知本(5) Zhiben(5) | 121.00 | 22.69 | 100 | 34 | 116.82 |
| | 41 | 紹家 Shaojia | 120.86 | 22.38 | 520 | 49 | 119.71 |
| | 42 | 霧鹿 Wulu | 121.04 | 23.17 | 910 | 45 | 102.15 |
| | 43 | 新武(3) Xinwu(3) | 121.13 | 23.13 | 420 | 39 | 112.55 |
| | 44 | 向陽(2) Xiangyang(2) | 120.99 | 23.25 | 2400 | 41 | 113.54 |

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**Table 5.4 4-hour Mean Annual Maximum Rainfalls in Taiwan (Sheet 3 of 3)**

| | No. | Name | Longitude | Latitude | Elevation (m) | N-years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|---|
| WRA | 45 | 卓麓(4) Zhuolu(4) | 121.27 | 23.30 | 210 | 39 | 121.73 |
| | 46 | 立山 Lishan | 121.31 | 23.43 | 180 | 43 | 120.09 |
| | 47 | 西林 Xilin | 121.43 | 23.82 | 200 | 37 | 141.87 |
| | 48 | 哇拉鼻 Walabi | 121.19 | 23.35 | 960 | 33 | 121.7 |
| | 49 | 馬太安 Mataian | 121.37 | 23.67 | 1000 | 34 | 150.15 |
| | 50 | 南山 Nanshan | 121.38 | 24.44 | 1050 | 41 | 88.13 |
| | 51 | 大濁水 Dazhuoshui | 121.74 | 24.33 | 48 | 35 | 152.34 |
| | 52 | 武塔 Wuta | 121.78 | 24.45 | 32 | 35 | 144.06 |
| | 53 | 藤枝(2) Tengzhi(2) | 120.76 | 23.07 | 1640 | 31 | 151.24 |
| | 54 | 天池 Tianchi | 120.92 | 23.28 | 2230 | 37 | 130.43 |
| | 55 | 民族 Minzu | 120.70 | 23.22 | 530 | 32 | 156.88 |
| CWB | 56 | 永康 Yongkang* | 120.22 | 23.04 | 8.1 | 18 | 118.58 |
| | 57 | 高雄 Gaoxiong* | 120.30 | 22.57 | 2.3 | 34 | 128.05 |
| | 58 | 玉山 Yushan | 120.95 | 23.49 | 3844.8 | 34 | 106.04 |
| | 59 | 阿里山 Ahlishan | 120.80 | 23.51 | 2413.4 | 34 | 185.25 |
| | 60 | 花蓮 Hualian | 121.60 | 23.98 | 16 | 34 | 124.94 |
| | 61 | 宜蘭 Yilan | 121.73 | 24.77 | 7.2 | 34 | 118.97 |
| | 62 | 恆春 Hengchun | 120.73 | 22.01 | 22.1 | 34 | 143.12 |
| | 63 | 臺東 Taidong | 121.13 | 22.75 | 9 | 34 | 117.54 |
| | 64 | 樸子 Puzi* | 120.23 | 23.47 | 8 | 22 | 114.75 |
| | 65 | 北門 Beimen* | 120.10 | 23.27 | 14 | 22 | 101.59 |
| | 66 | 下營 Xiaying* | 120.27 | 23.24 | 5 | 22 | 117.14 |

Note: * Stations were selected as the base stations for development of OIF.

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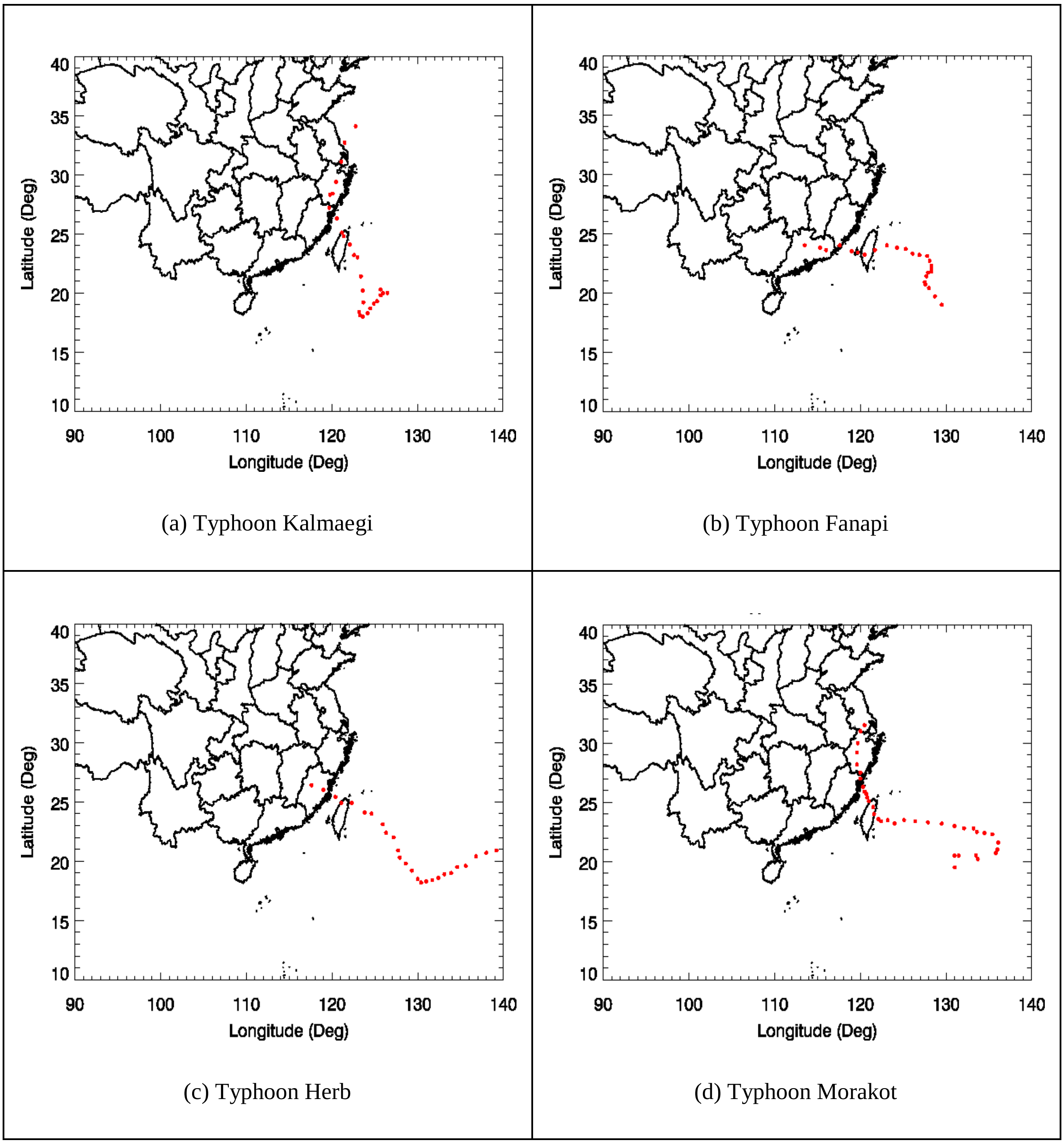
### 5.2.2 Typhoon Track

The tracks of typhoon Kalmaegi, Fanapi, Herb and Morakot are shown in Figure 5.9.




(a) Typhoon Kalmaegi

(b) Typhoon Fanapi

(c) Typhoon Herb

(d) Typhoon Morakot

**Figure 5.9 Tracks of Typhoon Kalmaegi, Fanapi, Herb and Morakot**

### 5.2.3 Moisture Flux during the Storm Period

The moisture flux of each storm during the lifespan is shown in Figure 5.10. For each storm, there existed a consistently strong southwest flow flux with respect to the storm centre, which was considered to be justified to storm transposition to Hong Kong.

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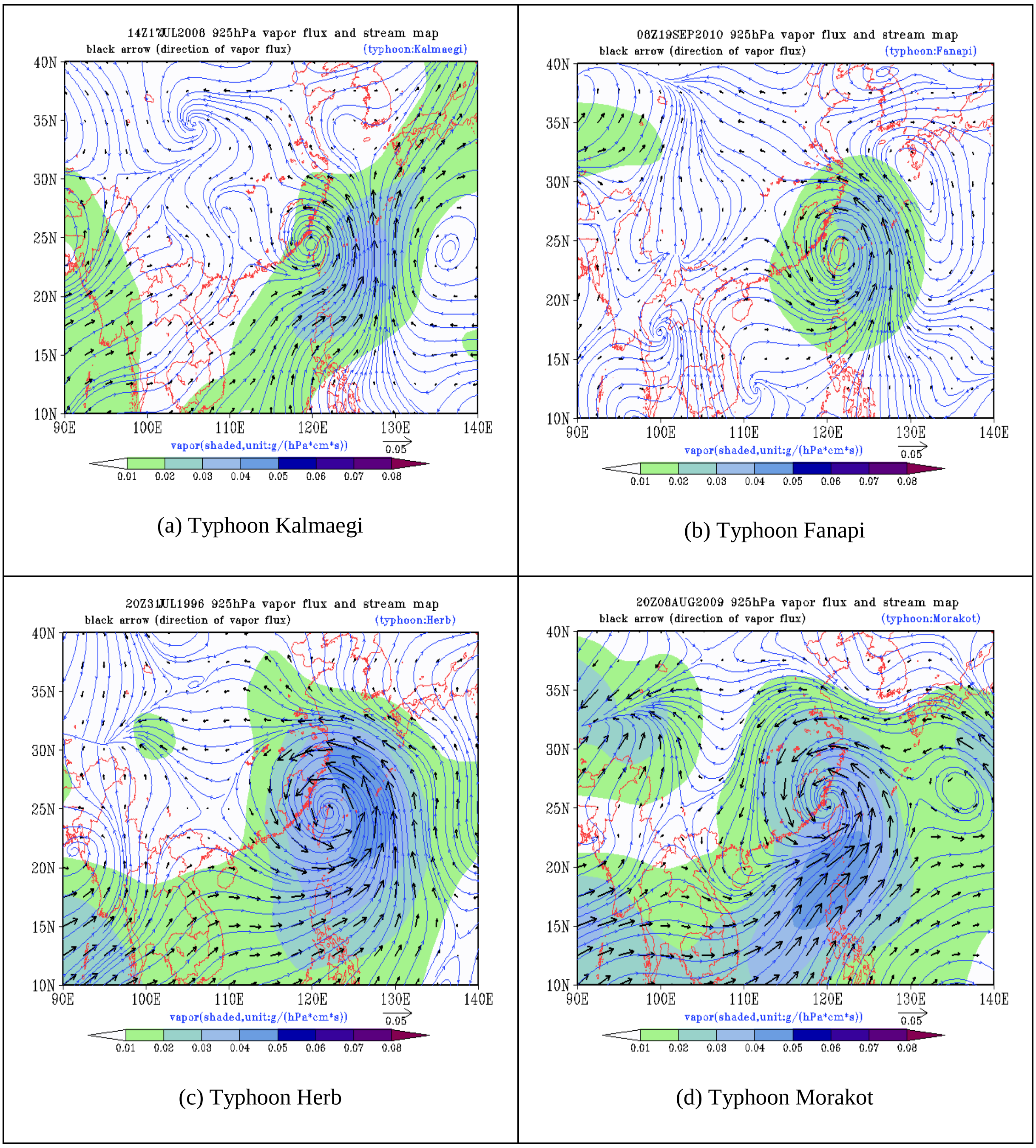


(a) Typhoon Kalmaegi

(b) Typhoon Fanapi

(c) Typhoon Herb

(d) Typhoon Morakot

**Figure 5.10 Moisture Flux of Typhoon Kalmaegi, Fanapi, Herb and Morakot**

### 5.2.4 Isohyet Map of 4-hour Maximum Rainfall for Each Storm

The maximum 4-hour rainfall for each storm was calculated by 4-hour moving window based on the hourly data provided by CWB. The maximum 4-hour rainfall isohyets maps for each storm are shown in Figure 5.11.

Combining the typhoon tracks and moisture flux, four storms (Kalmaegi, Fanapi, Herb and Morakot) were chosen to get a generalised convergence component in Taiwan to be transposed to Hong Kong.

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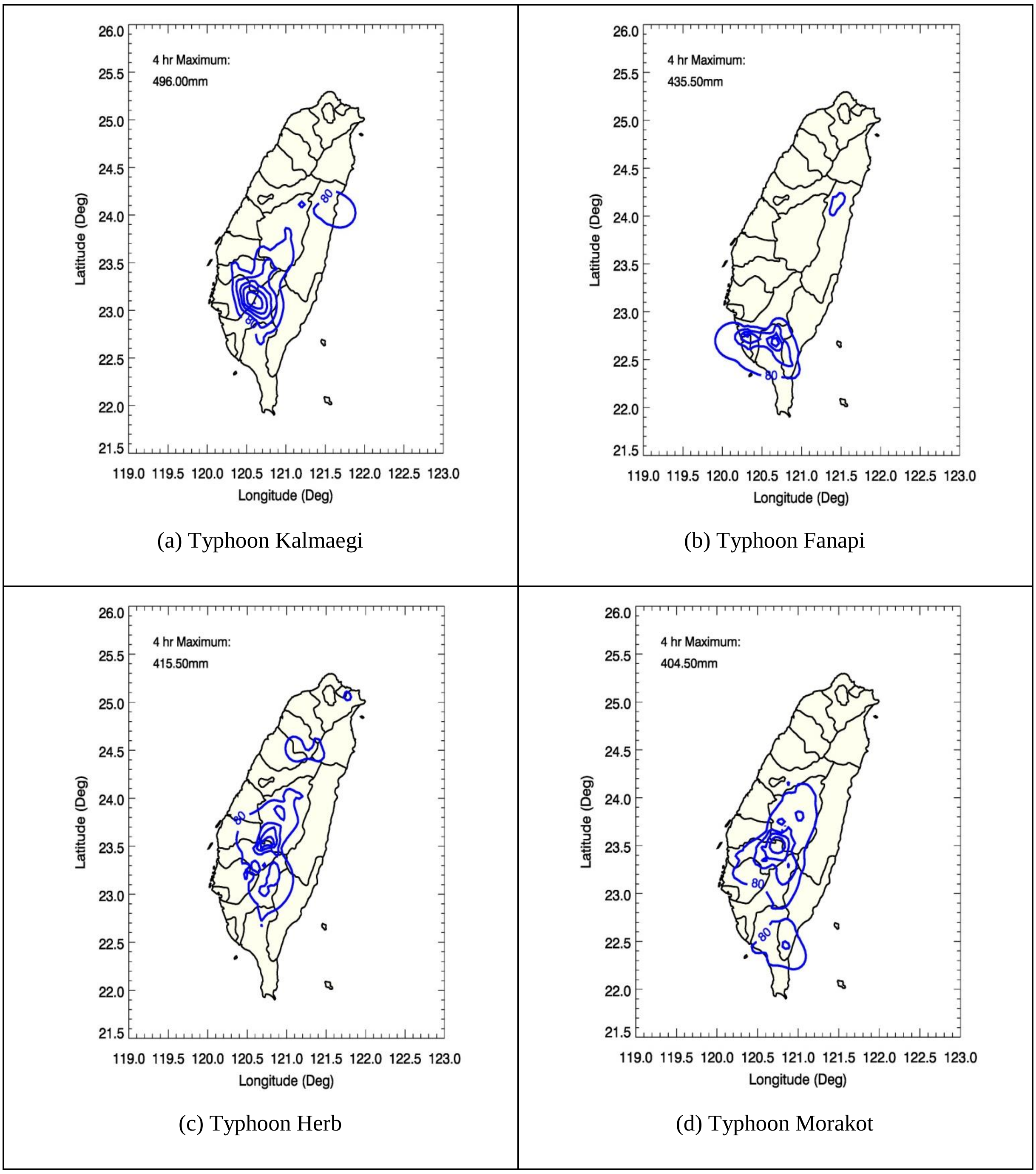


(a) Typhoon Kalmaegi (b) Typhoon Fanapi

(c) Typhoon Herb (d) Typhoon Morakot

**Figure 5.11 Maximum 4-hour Isohyets (> 80 mm) for Typhoon Kalmaegi, Fanapi, Herb and Morakot**

The SDOIF method was applied as a storm separation technique to decouple the Kalmaegi rainfall into two components, the convergence component and the orographic component. Also, the SDOIF method was applied to decouple the other three storms. The four convergence components were joined together to form a generalised pattern of the convergence component to be transposed to Hong Kong. The shape of the generalised pattern of the isohyets would be formed based on the four convergence components and its intensity was determined by the value of the Kalmaegi's convergence component.

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### 5.2.5 Development of the OIF for the Target Area

A total of five raingauge stations without orographic influence laying on the SW moisture flux route were selected as the base stations for the development of OIF. They are 永康 (No. 56 in Table 5.4), 高雄 (No. 57), 樸子 (No. 64), 北門 (No. 65) and 下營 (No. 66) with elevations less than 20 m in the southwest coastal area of Taiwan.

A gridded calculation frame covering the whole land area of Taiwan was adopted. Figure 5.13 shows the spatial distribution of the 4-hour OIF at a resolution of 5 km × 5 km for Taiwan that is in accordance with the pattern of the distribution of the 4-hour average annual maximum rainfall for Taiwan (Figure 5.12). The number in each grid (pixel) of Figure 5.13 indicates the OIF values for that grid.

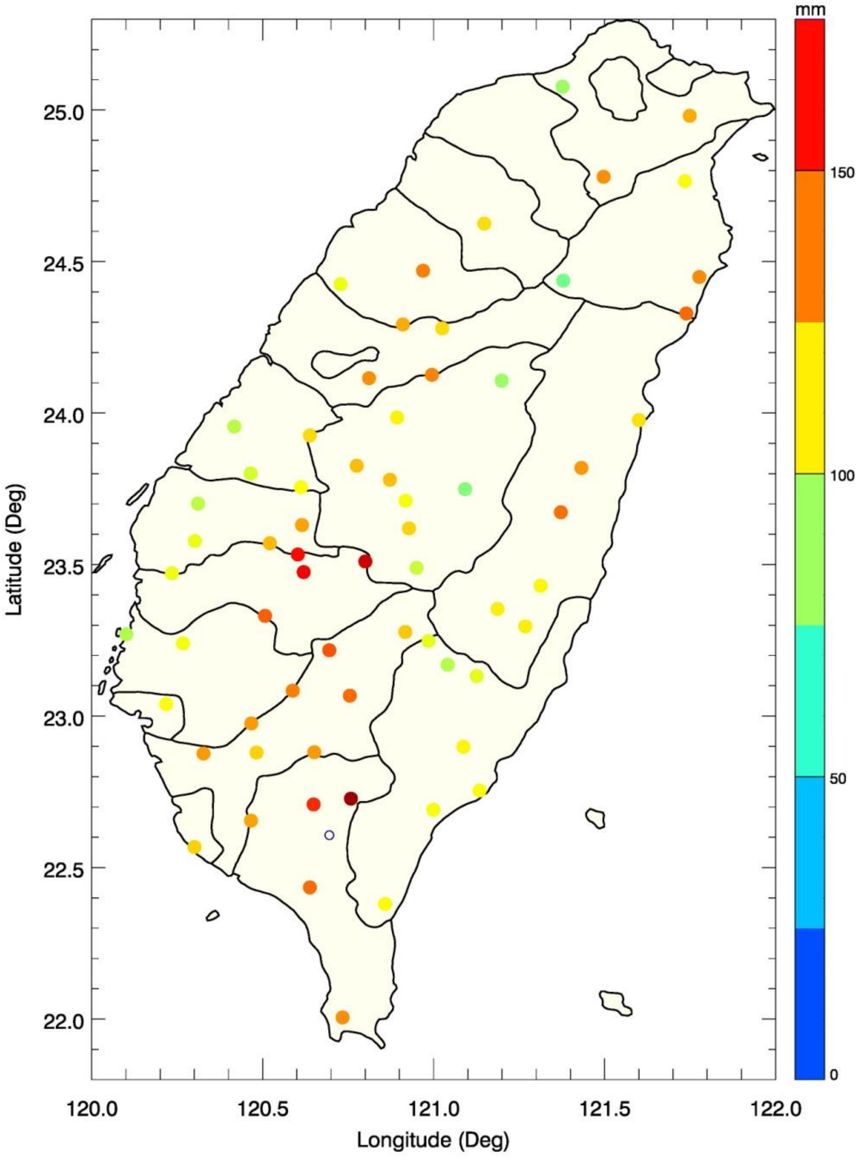


**Figure 5.12 4-hour Average Annual Maximum Rainfall in Taiwan**

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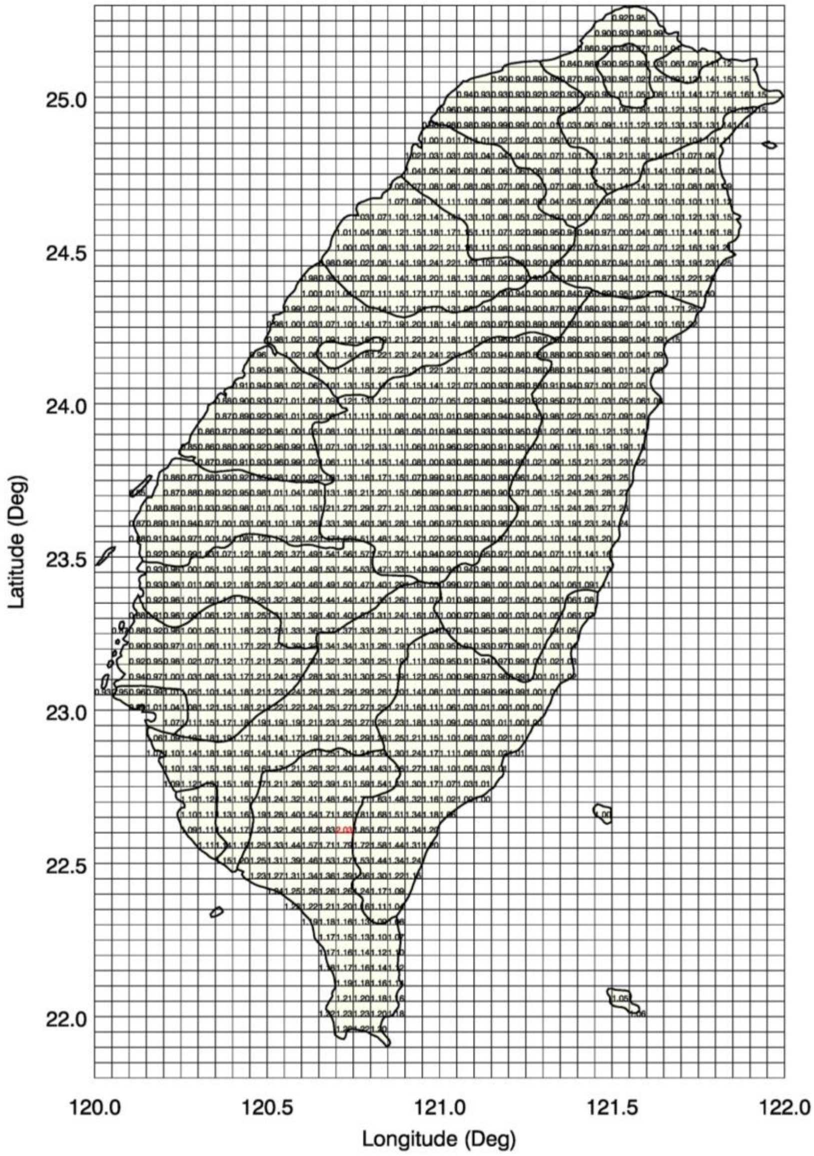


**Figure 5.13 4-hour OIF for Taiwan at a Resolution of 5 km × 5 km**

### 5.2.6 Development of Convergence Components for the Four Major Storms Affecting Taiwan

The 4-hour convergence component isohyets were generated by applying the 4-hour OIF (see Figure 5.13) to decouple the corresponding 4-hour isohyets based on Equation 1.12 of AECOM & Lin (2015) for the four major storms in Taiwan. The results of convergence component for the major four storms are given in Figure 5.14, based on the representative isohyets of 100 mm which exhibit high rainfall intensity with appropriate rainfall patterns at storm centre.

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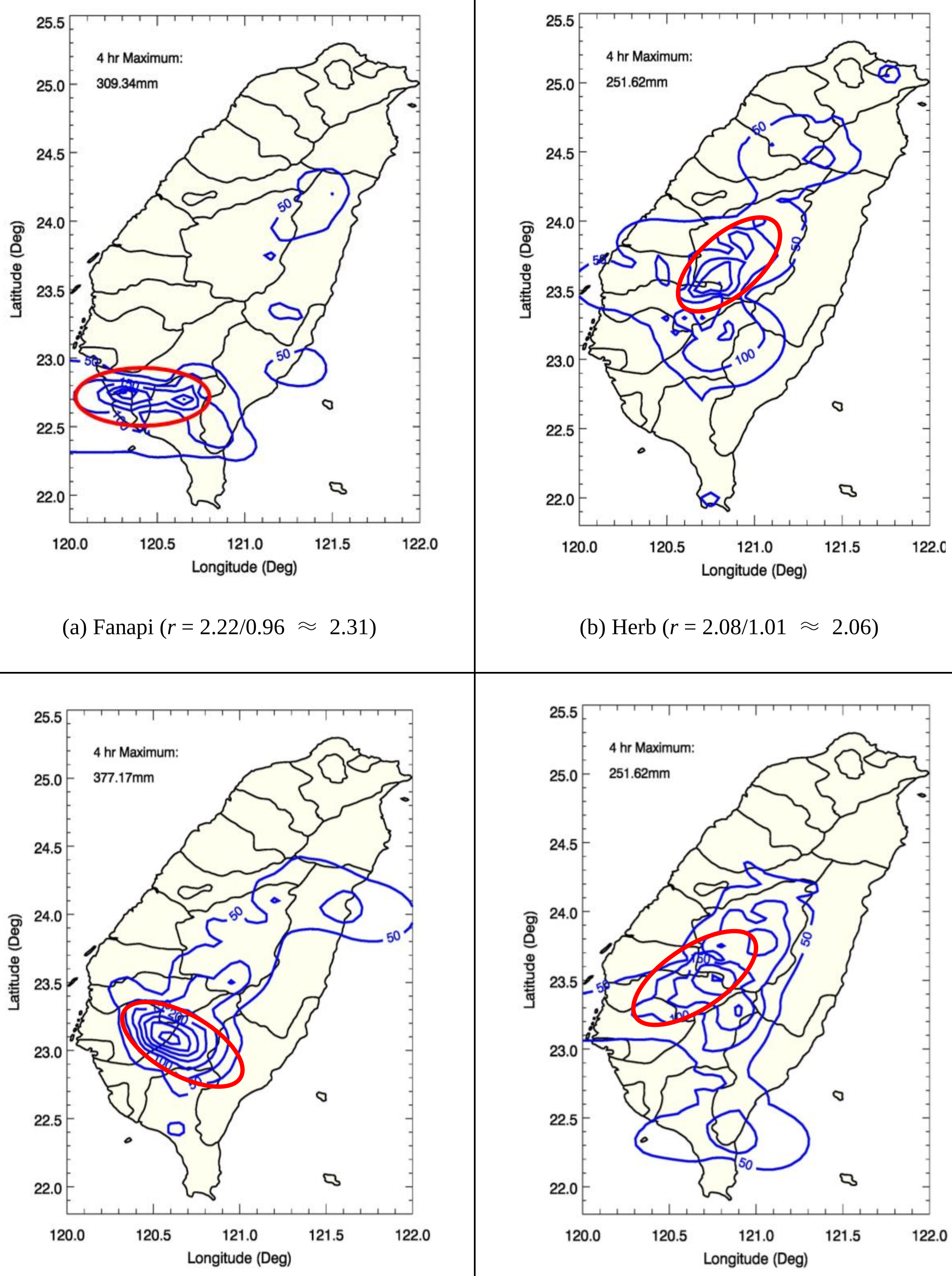


(a) Fanapi ($r$ = 2.22/0.96 ≈ 2.31)

(b) Herb ($r$ = 2.08/1.01 ≈ 2.06)

(c) Kalmaegi ($r$ = 2.2/1 ≈ 2.20)

(d) Morakot ($r$ = 2.28/1.01 ≈ 2.26)

Note: $r$ = major radius - minor radius.

**Figure 5.14 4-hour Convergence Component Isohyets of Typhoon Fanapi, Herb, Kalmaegi and Morakot**

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### 5.2.7 Development of the Relation of Area Average Rainfall with Area Size for Storms in Taiwan

The relation between the 4-hour average convergence area rainfall and the area size of the four major storms affecting Taiwan was developed as shown in Table 5.5.

**Table 5.5 Relation of 4-hour Average Generalised Convergence Area Rainfall with Area Size in Taiwan**

| Isohyets (mm) | Area ($km^2$) | | | | Generalised Convergence Component ($km^2$) |
|---|---|---|---|---|---|
| | Fanapi | Herb | Kalmaegi | Morakot | |
| 0-50 | 30190 | 21478 | 25985 | 24200 | 25985 |
| 50-100 | 4386 | 11465 | 7351 | 8137 | 7351 |
| 100-150 | 1240 | 3570 | 2390 | 4114 | 2390 |
| 150-200 | 484 | 726 | 756 | 1664 | 756 |
| 200-250 | 212 | 333 | 484 | 514 | 484 |
| 250-300 | 61 | 30 | 303 | 61 | 303 |
| 300-350 | 30 | | 363 | | 363 |
| 350-400 | | | 121 | | 121 |

### 5.2.8 Construction of Generalised Convergence Component Pattern of Transposed Storm in the Target Area, Taiwan

The generalised convergence component pattern was obtained by undertaking the following procedures:

(1) Development of the Depth-Area relation of the generalised convergence component.

(a) Convergence rainfall isohyets of the 4 major storms in Taiwan were drawn as shown in Figure 5.14.

(b) According to the convergence rainfall isohyets, the Depth-Area of the convergence pattern of 4-hour duration for the 4 major storms were developed as shown in Table 5.5.

(c) 4-hour convergence pattern of Kalmaegi was used for storm transposition.

(2) Determination of the shape of the generalised component pattern.

For the purpose of engineering design studies, a generalised pattern of the convergence component with reasonable shape and quantitative parameters is needed. The pattern of the isohyets over the four major storms was examined. The isohyets of 100 mm were used as the representatives for studying the shape of the generalised convergence component pattern.

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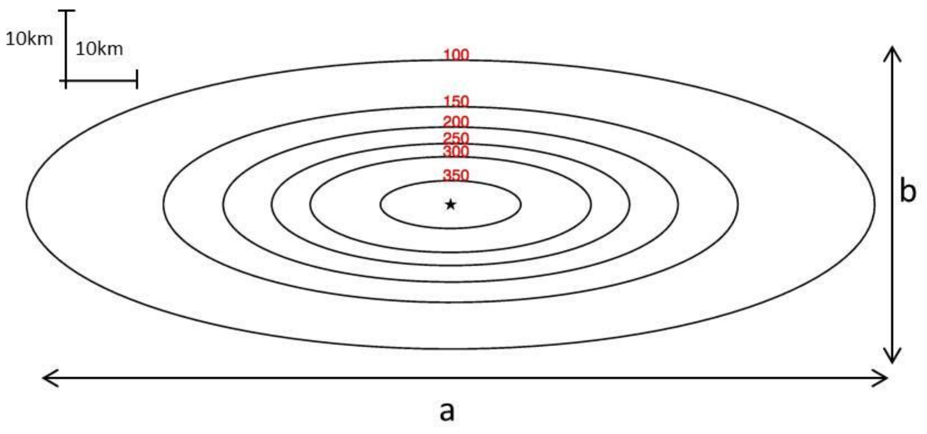
A working ellipse was drawn to match or rotate around the 100 mm isohyets as much as possible for each of the storms. The aspect ratios (i.e. the ratio of the major radius to the minor radius) for Fanapi, Herb, Kalmaegi and Morakot were estimated to be 2.31, 2.06, 2.20 and 2.26, respectively (See Figure 5.14). As a result, an elliptical shape of the generalised pattern with an aspect ratio of 2.2 was suggested.

(3) Construction of the generalised convergence component pattern

The generalised convergence component pattern of Taiwan storms was constructed with a size to cover the area of Hong Kong at the same scale as shown in Figure 5.15. The shape of the generalised convergence component pattern was determined with reference to the convergence components of the four major storms, Fanapi, Herb, Kalmaegi and Morakot, with the magnitudes of the pattern isohyets determined by the Kalmaegi. The centre value of the generalised convergence pattern was 377.2 mm from Kalmaegi. This makes the general isohyets pattern more flexible to use for different applications.




Note: Ratio, a:b = 2.2.

**Figure 5.15 4-hour Generalised Convergence Pattern for Taiwan Storms**

## 5.3 Comparison of the Convergence Rainfall of 9 October 1999 Storm in Fujian and the Generalised Convergence Pattern of Taiwan Storms

The Convergence Rainfall of Central Point for 9 October 1999 storm in Fujian and Typhoon Kalmaegi in Taiwan are 359.3 and 377.2 mm, respectively. The 9 October 1999 storm in Fujian was not selected for storm transposition in this study based on the following considerations:

(a) the centre value of 359.3 mm of the convergence component of the 9 October 1999 storm in Fujian is less severe than that of 377.2 mm for Kalmaegi Storm; and

(b) Dew point data for the 9 October 1999 storm in Fujian is not available, which is required for the calculation of moisture

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maximisation ratio. The moisture maximisation ratio is one of the transposition adjustments as part of the storm transposition analysis.

# 6 Storm Transposition and Orientation Adjustment

## 6.1 Development of 4-hour OIF for Hong Kong

*Hong Kong*

A total of 74 raingauge stations in Hong Kong with observation periods longer than 17 years were used in the computation of the local 4-hour OIF. The cut-off of 17 years was adopted with a view to maximising the use of the data while assuring the quality of statistical analysis in the application of SDOIF method. Comparing with the data used for the statistical method, the TMS and WGL raingauge stations were not selected for the analysis, because the location of TMS of 19 years is very close to N14 which has 32 years of data, which is the raingauge at the highest location in Hong Kong. The 4-hour mean annual maximum rainfall of the TMS station is much smaller than that of N14 due to statistical inaccuracy as a result of shorter sampling period. The WGL was discarded due to its dubiously low 4-hour mean annual maximum rainfall. Table 6.1 summarises the mean annual maximum rainfall values for the 74 raingauge stations in Hong Kong and Figure 6.1 shows their locations.

**Table 6.1 4-hour Mean Annual Maximum Rainfalls in Hong Kong (Sheet 1 of 3)**

| No. | ID | Longitude | Latitude | Elevation (m) | N-Years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|
| 1 | H01 | 114.12 | 22.27 | 107 | 31 | 130.74 |
| 2 | H02 | 114.13 | 22.28 | 95 | 32 | 129.48 |
| 3 | H03 | 114.13 | 22.26 | 132 | 32 | 123.81 |
| 4 | H04 | 114.14 | 22.28 | 123 | 32 | 132.98 |
| 5 | H05 | 114.16 | 22.25 | 103 | 32 | 129.91 |
| 6 | H06 | 114.18 | 22.27 | 88 | 32 | 130.67 |
| 7 | H07 | 114.19 | 22.25 | 94 | 31 | 118.69 |
| 8 | H08 | 114.19 | 22.26 | 129 | 32 | 130.02 |
| 9 | H09 | 114.20 | 22.29 | 160 | 32 | 128.39 |
| 10 | H10 | 114.15 | 22.28 | 530 | 32 | 129.77 |
| 11 | H12 | 114.15 | 22.28 | 188 | 32 | 127.41 |
| 12 | H14 | 114.23 | 22.26 | 141 | 32 | 126.73 |
| 13 | H15 | 114.22 | 22.22 | 50 | 32 | 117.14 |
| 14 | H16 | 114.15 | 22.27 | 439 | 32 | 134.31 |
| 15 | H17 | 114.16 | 22.27 | 200 | 32 | 127.72 |
| 16 | H18 | 114.22 | 22.28 | 77 | 32 | 131.66 |
| 17 | H19 | 114.23 | 22.28 | 53 | 32 | 126.31 |
| 18 | H20 | 114.15 | 22.24 | 104 | 32 | 121.95 |

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**Table 6.1 4-hour Mean Annual Maximum Rainfalls in Hong Kong (Sheet 2 of 3)**

| No. | ID | Longitude | Latitude | Elevation (m) | N-Years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|
| 19 | H21 | 114.19 | 22.24 | 139 | 30 | 117.77 |
| 20 | HKO HQ | 114.17 | 22.30 | 32 | 125 | 125.50 |
| 21 | K01 | 114.18 | 22.31 | 91 | 32 | 127.59 |
| 22 | K02 | 114.18 | 22.34 | 92 | 32 | 133.84 |
| 23 | K03 | 114.22 | 22.32 | 91 | 32 | 117.84 |
| 24 | K04 | 114.23 | 22.33 | 178 | 32 | 125.80 |
| 25 | K05 | 114.24 | 22.30 | 117 | 32 | 122.58 |
| 26 | K06 | 114.16 | 22.34 | 35 | 32 | 133.98 |
| 27 | K07 | 114.20 | 22.35 | 197 | 32 | 132.33 |
| 28 | K08 | 114.24 | 22.31 | 77 | 32 | 122.86 |
| 29 | N01 | 114.17 | 22.36 | 38 | 32 | 142.27 |
| 30 | N02 | 114.19 | 22.39 | 73 | 32 | 134.94 |
| 31 | N03 | 114.13 | 22.37 | 113 | 32 | 132.20 |
| 32 | N04 | 114.13 | 22.35 | 96 | 32 | 124.17 |
| 33 | N05 | 114.14 | 22.49 | 111 | 32 | 113.45 |
| 34 | N06 | 114.14 | 22.36 | 106 | 32 | 138.27 |
| 35 | N07 | 113.97 | 22.39 | 41 | 32 | 114.27 |
| 36 | N08 | 114.25 | 22.34 | 256 | 32 | 120.92 |
| 37 | N09 | 114.21 | 22.42 | 6 | 32 | 136.34 |
| 38 | N10 | 114.06 | 22.37 | 35 | 32 | 120.27 |
| 39 | N11 | 114.09 | 22.34 | 40 | 32 | 125.03 |
| 40 | N12 | 114.02 | 22.45 | 79 | 32 | 113.56 |
| 41 | N13 | 114.34 | 22.38 | 87 | 32 | 135.25 |
| 42 | N14 | 114.12 | 22.41 | 944 | 32 | 153.11 |
| 43 | N15 | 114.27 | 22.38 | 41 | 32 | 126.34 |
| 44 | N16 | 114.27 | 22.32 | 114 | 30 | 124.57 |
| 45 | N17 | 113.94 | 22.28 | 17 | 25 | 148.26 |
| 46 | N18 | 114.00 | 22.27 | 69 | 25 | 140.76 |
| 47 | R11 | 113.91 | 22.26 | 479 | 28 | 115.30 |
| 48 | R12 | 114.01 | 22.29 | 106 | 31 | 112.53 |
| 49 | R14 | 114.26 | 22.21 | 45 | 31 | 109.77 |
| 50 | R18 | 114.29 | 22.31 | 122 | 31 | 101.82 |
| 51 | R19 | 114.21 | 22.29 | 7 | 23 | 123.48 |
| 52 | R21 | 113.92 | 22.38 | 28 | 31 | 117.31 |
| 53 | R22* | 114.01 | 22.49 | 8 | 31 | 96.48 |
| 54 | R23 | 114.17 | 22.45 | 23 | 31 | 125.47 |
| 55 | R24 | 114.21 | 22.54 | 39 | 31 | 115.23 |
| 56 | R25 | 114.33 | 22.41 | 106 | 31 | 105.97 |
| 57 | R27 | 114.00 | 22.42 | 102 | 31 | 105.13 |
| 58 | R28 | 114.05 | 22.45 | 3 | 31 | 103.63 |
| 59 | R29 | 114.08 | 22.51 | 67 | 31 | 94.66 |

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**Table 6.1 4-hour Mean Annual Maximum Rainfalls in Hong Kong (Sheet 3 of 3)**

| No. | ID | Longitude | Latitude | Elevation (m) | N-Years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|
| 60 | R31 | 114.24 | 22.48 | 24 | 31 | 101.65 |
| 61 | CCH | 114.03 | 22.20 | 72 | 24 | 105.21 |
| 62 | EPC | 114.43 | 22.55 | 29 | 23 | 84.70 |
| 63 | JKB | 114.26 | 22.32 | 38 | 25 | 114.18 |
| 64 | KAT* | 114.30 | 22.54 | 10 | 17 | 107.53 |
| 65 | KP | 114.17 | 22.31 | 65 | 24 | 119.54 |
| 66 | LFS | 113.98 | 22.47 | 31 | 31 | 91.66 |
| 67 | PLC | 114.24 | 22.48 | 51 | 23 | 97.43 |
| 68 | SEK | 114.08 | 22.44 | 16 | 19 | 124.03 |
| 69 | SHA | 114.21 | 22.40 | 6 | 31 | 122.76 |
| 70 | SLW | 113.91 | 22.29 | 61 | 23 | 118.80 |
| 71 | TAP | 114.36 | 22.47 | 15 | 23 | 108.78 |
| 72 | TC | 114.22 | 22.36 | 572 | 18 | 113.47 |
| 73 | TKL | 114.16 | 22.53 | 15 | 28 | 109.04 |
| 74 | TYW | 114.32 | 22.40 | 5 | 21 | 116.38 |

Note: * Base station for development of OIF.

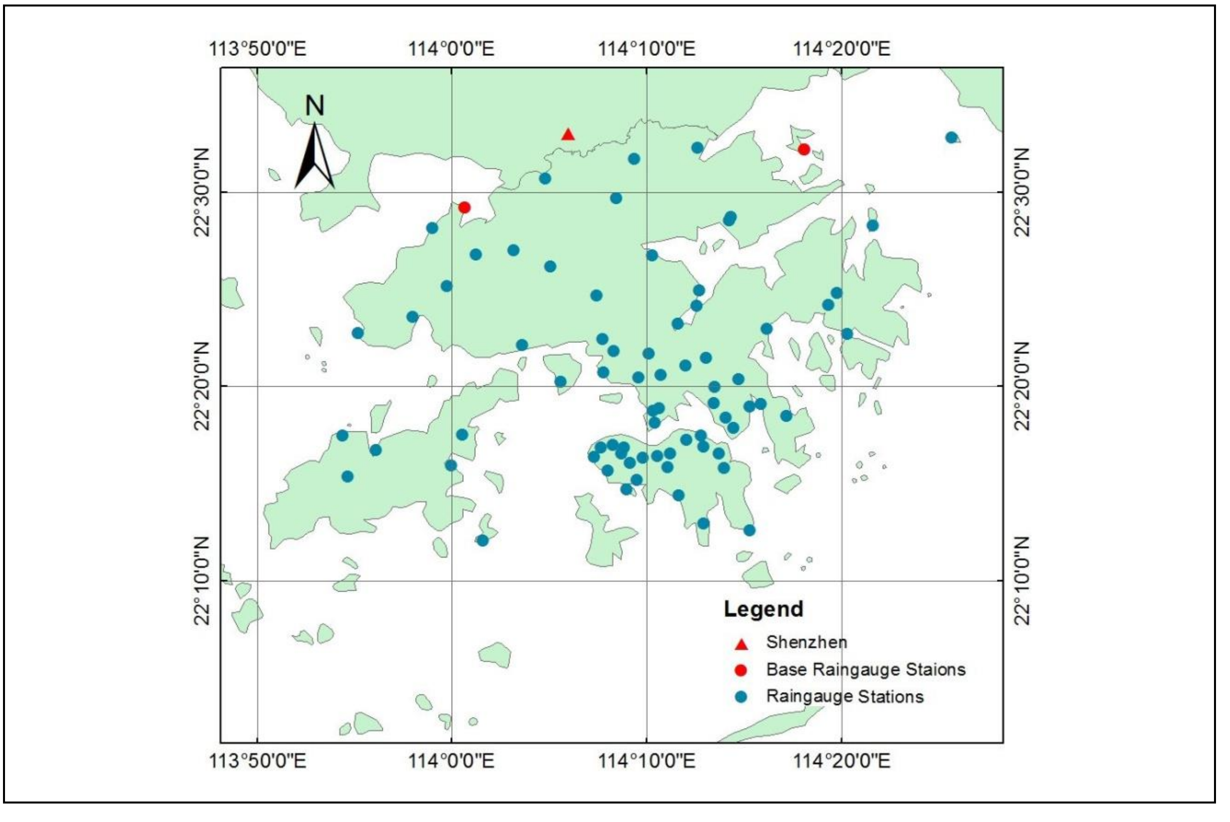


**Figure 6.1 Locations of the Raingauge Stations for the Computation of Local 4-hour OIF**

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*South Guangdong*

Data of the five South Guangdong (SGD) raingauge stations were studied in detail. Out of these five stations, only Shenzhen is located relatively close to Hong Kong and was therefore considered in developing the OIF pattern. The mean 4-hour rainfall of Shenzhen is listed in Table 6.2, and its location is shown in Figure 6.1.

**Table 6.2 4-hour Mean Annual Maximum Rainfalls at Shenzhen**

| No. | ID | Longitude | Latitude | Elevation (m) | N-years | 4-hour Mean Annual Maximum Rainfall (mm) |
|---|---|---|---|---|---|---|
| 1 | Shenzhen | 114.10 | 22.55 | 27 | 23 | 111.87 |

The Shenzhen raingauge station together with two Hong Kong raingauge stations, KAT and R22 serve as the base stations in developing the local OIF pattern. Those base stations were stations without orographic influence referring to Section 1.3.2.2 in AECOM and Lin (2015). Their locations are shown in Figure 6.1.

Figure 6.2 shows the spatial distribution of the 4-hour OIF for Hong Kong at a resolution of 5 km × 5 km.

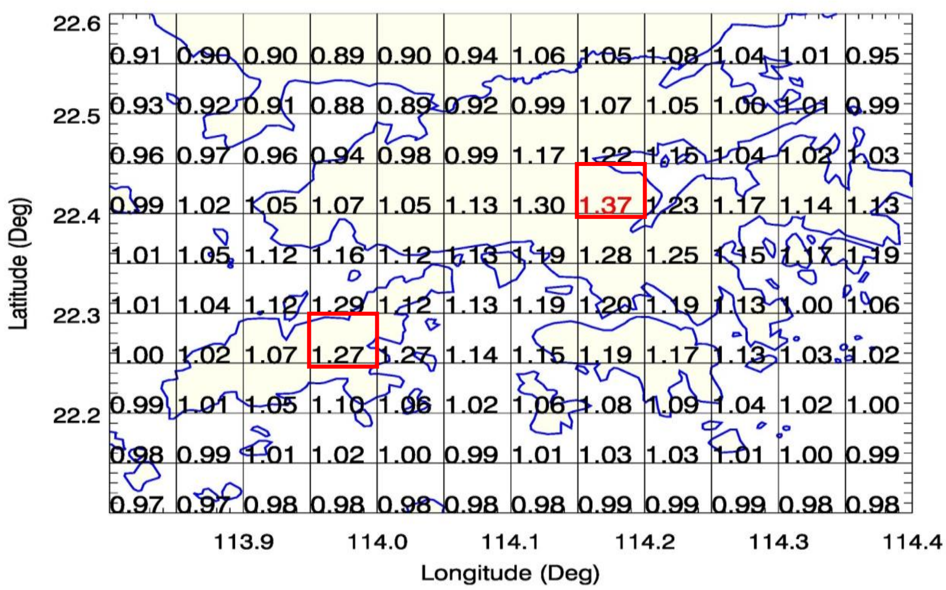


**Figure 6.2 4-hour OIF for Hong Kong at a Resolution of 5 km × 5 km**

## 6.2 The Comparisons of 24-hour and 4-hour OIF for Hong Kong

The 4-hour OIF pattern (see Figure 6.2) is slightly different with the 24-hour OIF

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pattern (see Figure 6.3) for Hong Kong, especially in Lantau Island, where the highest OIF was 1.37 and 1.27 for 24-hour and 4-hour respectively (highlighted in Figures 6.2 and 6.3). The reasons are as follows:

(a) The data used for 24-hour and 4-hour are different. There were 66 raingauge stations with data length till 2010 used for developing the 24-hour OIF pattern including the base stations R22, R30 and Shenzhen, while there are 74 raingauge stations with data length till 2015 used for developing 4-hour OIF pattern including the base stations R22, KAT and Shenzhen. The locations of those stations are given in Figure 6.4 which shows that one station at SLW is added to calculate the 4-hour OIF at Lantau Island. Detailed information of the base stations is given in Table 6.3. The data of R30 was replaced by KAT because the data of R30 were not provided in this study and KAT is very close to R30 in location. Therefore, the use of different base stations and data series slightly affect the resulting OIF pattern of 24-hour and 4-hour PMP studies.

(b) Rainfall affected by orographic intensification is also governed by several factors such as the storm type, duration, etc. Given the same storm, the orographic effect increases with duration of rainfall concerned.

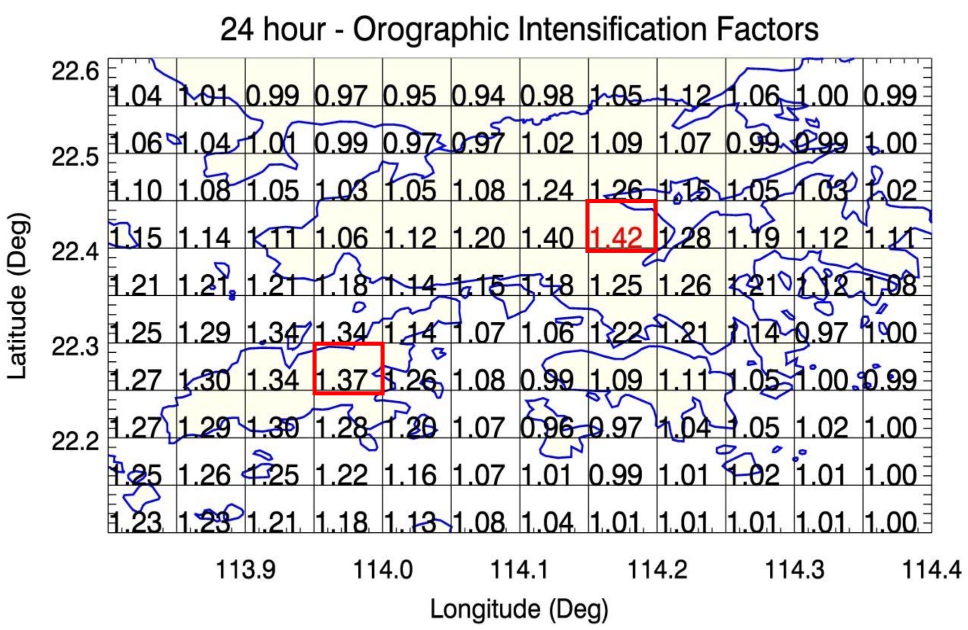


**Figure 6.3 The 24-hour OIF Pattern for Hong Kong at a Resolution of 5 km × 5 km (AECOM and Lin, 2015)**

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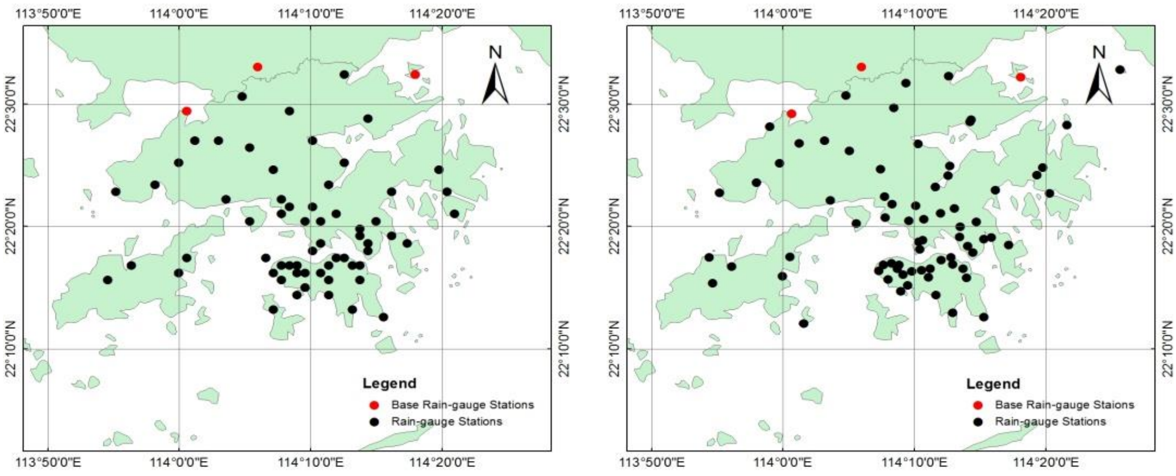


(a) 24-hour (b) 4-hour

**Figure 6.4 The Locations of the Raingauge Stations for Calculating the 24-hour and 4-hour OIF Pattern in Hong Kong**

**Table 6.3 Detailed Information of Base Stations Adopted for 24-hour and 4-hour PMP Updating Study**

| | ID | Locations | Longitude | Latitude | Elevation (m) | Time Period |
|---|---|---|---|---|---|---|
| 24-Hour | R22 | Tsim Bei Tsui | 114.01 | 22.49 | 8 | 1987-2010 |
| | R30 | Kat O Fisheries Research Sub-Station | 114.30 | 22.54 | 10 | 1987-2008 |
| | Shenzhen | Shenzhen | 22.55 | 114.10 | 27 | 1981-2005 |
| 4-Hour | R22 | Tsim Bei Tsui | 114.01 | 22.49 | 8 | 1985-2015 |
| | KAT | Kat O | 114.30 | 22.54 | 10 | 1993-2015 |
| | Shenzhen | Shenzhen | 22.55 | 114.10 | 27 | 1981-2005 |

## 6.3 Storm Transposition and Orientation Adjustment

The generalised convergence component pattern of Taiwan storms was coupled with the local SDOIF pattern or orographic component to generate a PMP embryo by superposing the generalised convergence component pattern onto the local SDOIF. The word “embryo” denotes a preliminary PMP estimate. It is required to adjust this embryonic PMP by transposition adjustments in order to consider the orientations to the prevailing moisture inflow jet during the invasion of typhoon storm to Hong Kong.

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### 6.3.1 Storm Transposition

The generalised convergence component pattern of Taiwan storms as shown in Figure 5.15 was superposed on the local OIF grids to calculate the PMP fraction or portion at each grid. As an example, the generalised convergence pattern superposed on the OIF grid cell centred at Tai Mo Shan is illustrated in Figure 6.5.

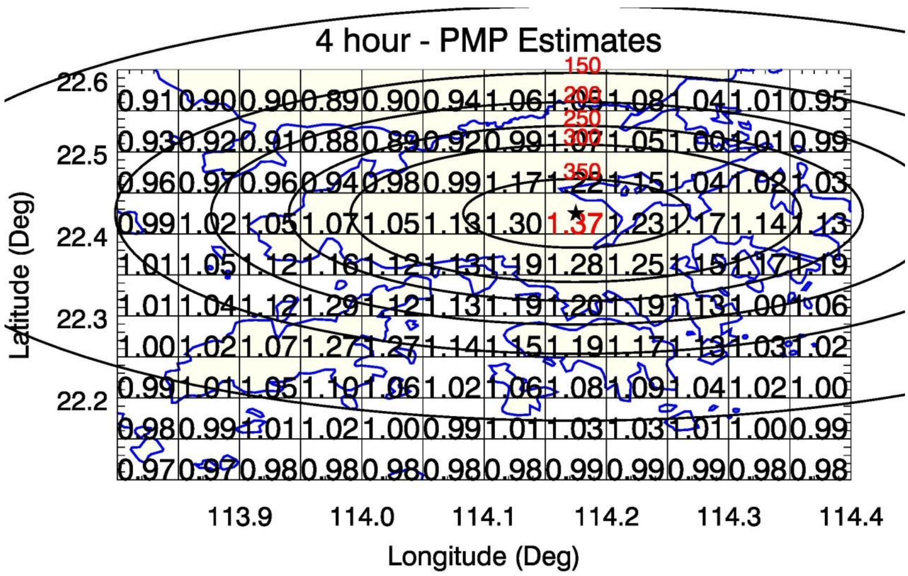


**Figure 6.5 Generalised Convergence Component Pattern Superposed on OIF Grid Centred at Tai Mo Shan (E-W Orientation 0°)**

### 6.3.2 Orientation Adjustment

The orientation of a potential PMP-level storm in the future is not predictable. The worst scenario should be considered in the PMP estimation. Therefore, a number orientations for the major ellipse axis of the generalised convergence pattern from 0° to 180° at an increment of 22.5° (in anticlockwise direction) were studied. They are 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5° and 180° (identical to 0°). The orientation of 77.5° was also calculated because of the convergence component contour of Herb and Morakot displaying the North-North-East. An example showing the rotated generalised convergence pattern superposing the local OIF grids is given in Figure 6.6. A complete set of the orientation of convergence pattern centred at Tai Mo Shan and Lantau Island is given in Appendix C.

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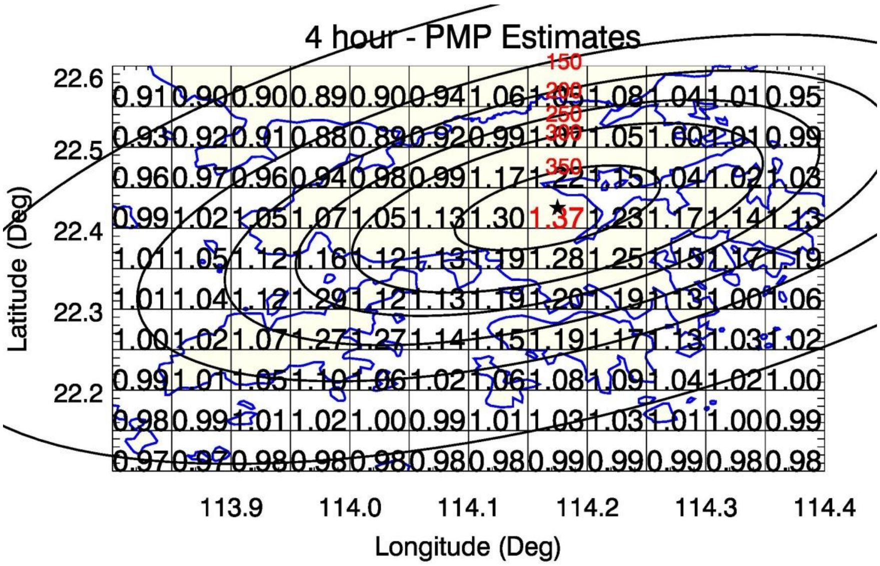


**Figure 6.6 Generalised Convergence Component Pattern Superposed on OIF Grid for Tai Mo Shan with 22.5° Orientation Adjustment Centred at Tai Mo Shan**

## 6.4 Embryonic PMP

After the orientation adjustment of the convergence pattern was applied to the gridded PMP fractions (OIF), embryonic PMP can be obtained for the nine selected orientation adjustment directions. An example of the embryonic PMP centred at Tai Mo Shan with 22.5° orientation adjustment is given in Figure 6.7. The embryonic PMP in grids and isohyets with the generalised convergence pattern centred at Tai Mo Shan and Lantau Island for a complete set of orientation adjustments are given in Appendices D and E.

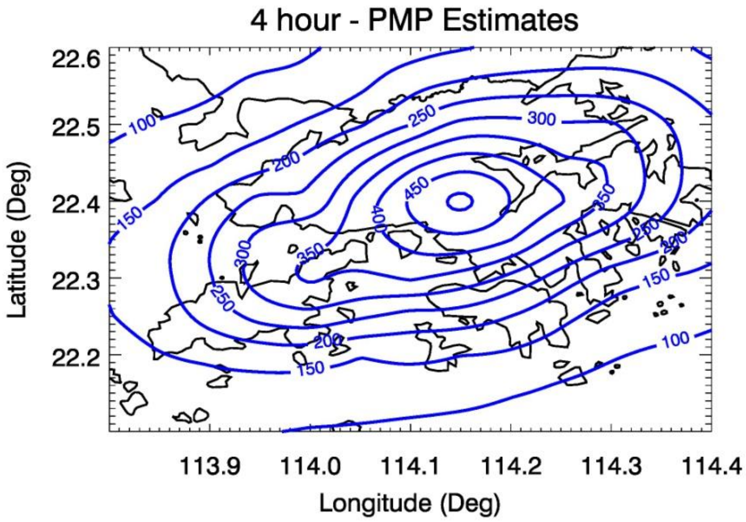


**Figure 6.7 Isohyets of Embryonic 4-hour PMP Centred at Tai Mo Shan with Orientation Adjustment of 22.5°**

## 6.5 The Centre Point Value of the Embryonic PMP

No matter what orientation is, the center point value of the embryonic PMP is the same. The center point values of the embryonic PMP estimates are derived as follows:

Centre point value of 4-hour embryonic PMP
= the highest grid value of OIF map × the highest center value of the 4-hour convergence component of Kalmaegi.

Then, the embryonic PMP
= 1.37 × 377.17 = 516.7 mm (centred at Tai Mo Shan area (the highest OIF cell for the entire Hong Kong)).

If centred at Lantau Island, the embryonic PMP
= 1.27 × 377.17 = 479.0 mm (centred at the highest OIF cell at Lantau Island).

# 7 Moisture Maximisation for Transposed Storm

## 7.1 Basics

In storm transposition, the moisture adjustment is the transposed storm rainfall amounts of target area, i.e. Taiwan, multiplied by the ratio of precipitable water for the enveloping, or historical maximum dew point in the design location ($W_2$), i.e. Hong Kong, to the precipitable water for the representative storm dew point ($W_1$) in the target area, or

$$R_2 = R_1\left(\frac{W_2}{W_1}\right) \quad \text{.................................................... (7.1)}$$

where $R_1$ is the transposed storm rainfall for a particular duration and size of area and $R_2$ is the storm rainfall adjusted for transposition to the design area.

In maximising the rainfall due to moisture, the maximum dew point was used at the same location as that of the representative storm dew point. The historical maximum persisting 12-hour dew points based on 6-hour interval dew point observations are commonly used for moisture maximisation if the available dew point data series is longer than 50 years, or 100-year return period value of frequency analysis is used as maximum values representative of maximum atmospheric moisture if the annual dew point record series is much shorter than 50 years. Dew points selected at locations between the rain area and moisture source tend to be more representative of the atmospheric moisture content, or precipitable water, flowing into the storm area. To reduce sampling error, an average over the dew point locations (sites) near the storm centre in the moisture inflow course, is recommended.

## 7.2 Representative Storm Dew Point ($W_1$) in the Target Area, Taiwan

Yongkang (永康, 56) and Gaoxiong (高雄, 57), referring to Figure 3.1, in the

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Southwest moisture inflow direction during Kalmaegi storm, were selected to be the representative dew point stations. The resulting representative maximum 12-hour persisting dew points, adjusted to 1,000 hPa, was 23.0°C, which corresponded to precipitable water of 67.80 mm under assumption of pseudo-adiabatic atmosphere.

## 7.3 Historical Maximum 12-hour Persisting Dew Point in the Design Area, Hong Kong

### 7.3.1 Data Selection

The HKO HQ which is the only station in Hong Kong having historical dew point data of 125 years (data available between 1884 and 2015, 1940-1946 data were missing due to the Word War Ⅱ) was chosen for calculation of the historical 12-hour maximum persisting dew point, which was then converted to the corresponding 1,000 hPa dew point. Details of the data screening process are listed as follows:

(a) Select each single observation greater than the pre-set threshold (25°C);

(b) Use a 12-hour window to pick up the maximum persisting 12-hour dew point between the year 1884 and year 2015 to form an Annual Maximum Series (AMS);

(c) Check to ensure that the 12-hour persisting dew point are derived from a period of 24-hour prior to the onset of the corresponding major rainfall; and

(d) Obtain a dew point series of 125-year for the period between 1884 and 2015 for frequency analysis.

### 7.3.2 Frequency Analysis

The 100-year return period of the historical 12-hour maximum persisting dew point at HKO HQ, calculated based on the methodology presented in Lin et al. (2006), was 27.11°C. The corresponding 1,000 hPa dew point is 27.24°C corresponding to precipitable water of 97.12 mm under the assumption of pseudo-adiabatic atmosphere.

## 7.4 Adjustment to the Precipitable Water under Assumption of Pseudo-adiabatic Atmosphere Maximisation

According to 陳宏 et al. (2014), there is an error of overestimation in the calculation of precipitable water by using pseudo-adiabatic method in comparison of hierarchical integral humidity, which is considered more accurate. Therefore, an adjustment of the precipitable water in Taiwan and Hong Kong was made to correct the overestimation. The resulting precipitable water for Taiwan and Hong Kong was 58.45 mm and 81.43 mm respectively.

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### 7.5 Ratio of Moisture Maximisation

The ratio for moisture adjustment for storm transposition is the ratio of precipitable water $W_2$ for the maximum dew point at the transposed location (the design location which is Hong Kong in this Study) to the precipitable water $W_1$ for the representative storm (the Kalmaegi storm in Taiwan in this Study) dew point. Then, the storm rainfall amount $R_2$ adjusted for transposition for a particular duration and size at design location was obtained using Equation 7.1.

Ratio of moisture maximisation for transposition is estimated as follows:

$$r = W_2 / W_1 = 81.43 / 58.45 = 1.39$$

where $W_2$ = adjusted precipitable water for the historical maximum 12-hour persisting dew point for the design area of Hong Kong, which is 27.24°C

$W_1$ = adjusted precipitable water for the representative dew point, 23.0°C, for the Kalmaegi storm.

### 7.6 Estimated 4-hour PMP for Hong Kong

If the embryonic PMP is superposed at Tai Mo Shan, the centre point value is:

$$516.72 \text{ mm} \times 1.39 = 718.2 \text{ mm}$$

The corresponding 4-hour PMP isohyets centred at Tai Mo Shan with 22.5° orientation adjustment for Hong Kong are shown in Figure 7.1.

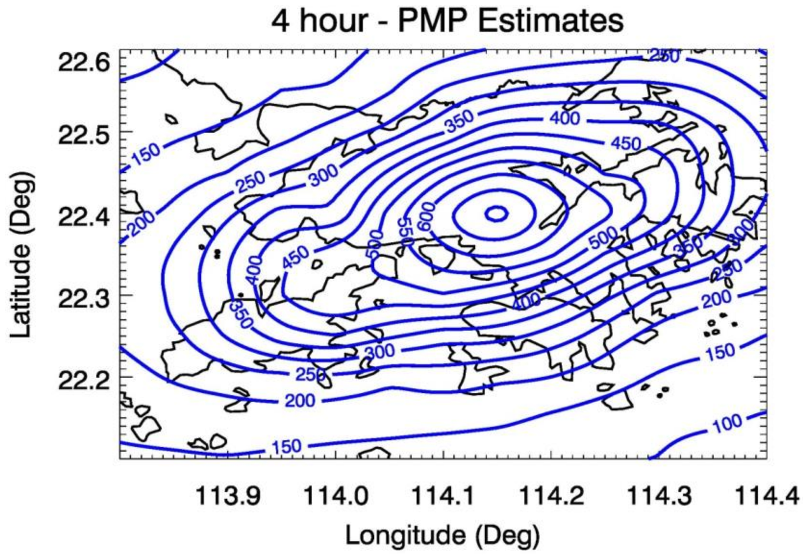


**Figure 7.1 The 4-hour PMP Isohyets Centred at Tai Mo Shan with Moisture Maximisation and Orientation Adjustment of 22.5° for Hong Kong**

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If the embryonic PMP is superposed at Lantau Island, the centre point value is:

479.00 mm × 1.39 = 665.8 mm

The corresponding 4-hour PMP isohyets centred at Lantau Island with 22.5° orientation adjustment for Hong Kong are shown in Figure 7.2.

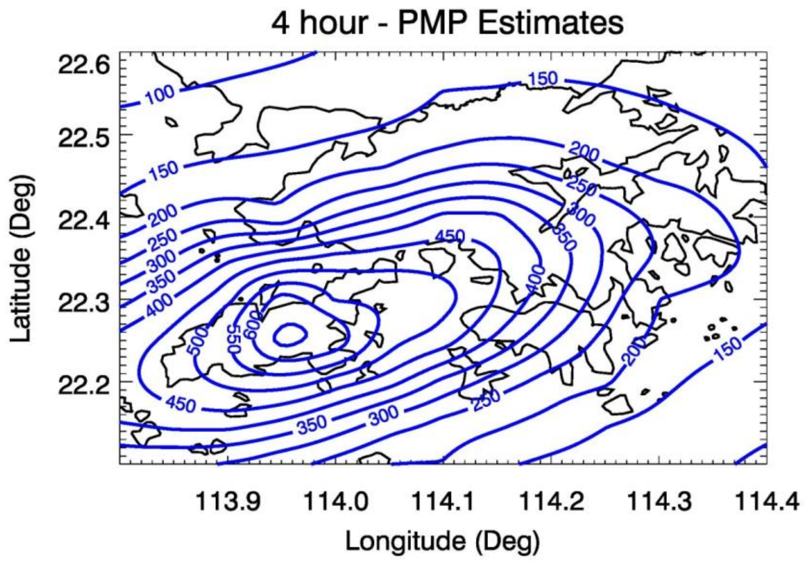


**Figure 7.2 The 4-hour PMP Isohyets Centred at Lantau Island with Moisture Maximisation and Orientation Adjustment of 22.5° for Hong Kong**

The embryonic PMP in grids and isohyets with the generalised convergence pattern centred with moisture maximisation at Tai Mo Shan and Lantau Island for a complete set of orientation adjustments are given in Appendix F.

## 7.7 Depth-Area Relation for the Estimated PMP for Hong Kong

The Depth-Area relation for the PMP estimate was obtained by superposing the moisture maximised embryonic storm to the range of Longitude and Latitude that cover the whole Hong Kong (see Table 7.1). Five scenarios for orientation: (a) the East-West orientation specified as E-W; (b) the ENE-WSW or 22.5°; (c) the NE-SW or 45°; (d) the NNE-SSW or 67.5° and (e) 77.5° for the major ellipse axis of the convergence pattern are given in Tables 7.2 and 7.3, when they are superposed on Hong Kong (i.e. centred at Tai Mo Shan and Lantau Island).

Calculations of the present study show that the orientation of 22.5° centred at Tai Mo Shan would produce the highest rainfall (see also Figure 7.1).

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**Table 7.1 The Range of Longitude and Latitude Covering the Whole Hong Kong Area**

| | Lower Bound (°) | Upper Bound (°) | Range (°) |
|---|---|---|---|
| Longitude | 113.8 | 114.4 | 0.6 |
| Latitude | 22.1 | 22.6 | 0.5 |

Notes: (1) 1° ～ 100 km.
(2) Area ～ 3,000 $km^2$ (including the ocean area).

**Table 7.2 Relation of Depth-Area of the 4-hour Embryonic PMP for Hong Kong Centred at Tai Mo Shan**

| Area ($km^2$) | Orientation of Major Storm Axis | | | | |
|---|---|---|---|---|---|
| | E-W 0° | ENE-WSW 22.5° | NE-SW 45° | NNE-SSW 67.5° | N-S 77.5°* |
| | Depth (mm) | Depth (mm) | Depth (mm) | Depth (mm) | Depth (mm) |
| 0 | 718.2 | 718.2 | 718.2 | 718.2 | 718.2 |
| 10 | 685.5 | 689.3 | 687.8 | 688.2 | 689.0 |
| 20 | 680.0 | 684.1 | 682.3 | 683.1 | 683.9 |
| 50 | 664.5 | 669.2 | 666.6 | 668.3 | 669.3 |
| 100 | 641.0 | 646.6 | 642.7 | 645.9 | 647.0 |
| 150 | 620.0 | 626.5 | 621.5 | 625.8 | 626.9 |
| 200 | 601.3 | 608.4 | 602.7 | 607.9 | 608.8 |
| 300 | 569.8 | 578.0 | 571.2 | 577.5 | 577.8 |
| 400 | 544.8 | 553.5 | 546.4 | 553.0 | 552.5 |
| 500 | 524.6 | 533.6 | 526.4 | 533.0 | 531.4 |
| 600 | 507.9 | 517.1 | 510.1 | 516.2 | 513.4 |
| 700 | 493.7 | 502.9 | 496.3 | 501.6 | 497.8 |
| 800 | 481.1 | 490.3 | 484.1 | 488.4 | 483.6 |
| 900 | 469.5 | 478.6 | 472.8 | 476.1 | 470.3 |
| 1000 | 458.3 | 467.4 | 461.8 | 464.2 | 457.7 |
| 1500 | 402.5 | 411.5 | 405.5 | 404.1 | 396.4 |
| 2000 | 351.6 | 359.6 | 351.8 | 349.2 | 343.1 |
| 3000 | 285.3 | 289.6 | 282.3 | 278.0 | 274.3 |

Notes: (1) * The orientation of 77.5° was also calculated because of the convergence component contour of Herb and Morakot displaying the North-North-East.
(2) The embryonic PMP with orientation adjustment of 90°, 112.5°, 135° and 157.5° are less critical and not shown here for clarity.

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**Table 7.3 Relation of Depth-Area of the 4-hour Embryonic PMP for Hong Kong Centred at Lantau Island**

| Area ($km^2$) | Orientation of Major Storm Axis | | | | |
|---|---|---|---|---|---|
| | E-W 0° | ENE-WSW 22.5° | NE-SW 45° | NNE-SSW 67.5° | N-S 77.5°* |
| | Depth (mm) | Depth (mm) | Depth (mm) | Depth (mm) | Depth (mm) |
| 0 | 665.8 | 665.8 | 665.8 | 665.8 | 665.8 |
| 10 | 645.6 | 646.1 | 647.3 | 643.5 | 645.8 |
| 20 | 641.0 | 641.5 | 642.7 | 639.0 | 641.2 |
| 50 | 627.9 | 628.3 | 629.6 | 626.0 | 628.2 |
| 100 | 607.9 | 608.2 | 609.7 | 606.0 | 608.1 |
| 150 | 589.9 | 590.4 | 591.9 | 588.1 | 589.9 |
| 200 | 573.7 | 574.6 | 576.0 | 572.0 | 573.4 |
| 300 | 546.2 | 548.0 | 549.1 | 544.3 | 544.9 |
| 400 | 523.8 | 526.7 | 527.3 | 521.6 | 521.2 |
| 500 | 505.2 | 509.3 | 509.4 | 502.6 | 501.3 |
| 600 | 489.5 | 494.7 | 494.1 | 486.4 | 484.0 |
| 700 | 475.6 | 481.8 | 480.6 | 472.1 | 468.8 |
| 800 | 463.0 | 469.9 | 468.2 | 459.0 | 455.0 |
| 900 | 451.2 | 458.5 | 456.4 | 446.7 | 442.2 |
| 1000 | 439.8 | 447.2 | 444.7 | 434.8 | 429.9 |
| 1500 | 382.8 | 387.7 | 384.7 | 376.2 | 371.4 |
| 2000 | 331.4 | 333.2 | 330.5 | 324.2 | 320.6 |
| 3000 | 262.6 | 268.0 | 265.5 | 254.6 | 249.5 |

Notes:
(1) * The orientation of 77.5° was also calculated because of the convergence component contour of Herb and Morakot displaying the North-North-East.
(2) The embryonic PMP with orientation adjustment of 90°, 112.5°, 135° and 157.5° are less critical and not shown here for clarity.

# 8 Application of PMP to Landslide Risk Assessment

## 8.1 Approach

Theoretically, the generalised convergence component from the target area (Taiwan) can be superimposed on any OIF grid cell for the design area (Hong Kong) to generate an individual PMP estimate for each cell. The worst scenario involving all possible locations and orientations could be adopted to obtain the most critical PMP estimate.

## 8.2 Application

Figure 8.1 shows the DAD curves of PMP estimates in Hong Kong and recent severe rainstorms. The PMP estimates based on storm transposition centred at Tai Mo Shan and oriented at 22.5° are shown and denoted as black solid line. The DAD curve of the previous

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PMP estimates in 1968 (Bell & Chin, 1968) and 2000 (HKO, 2000) are also plotted in the figure. The PMP estimates in 1968 are greater than that in 2000. There is a significant increase in 4-hour rainfall from 516 mm to 689.3 mm for a rainfall area of 10 km$^2$. In addition, the DAD curves of the storm at 7 June 2008 (the most severe 4-hour storm in Hong Kong between 1984 and 2015) and storm of 21 May 2016 (the most severe 4-hour storm in Hong Kong in 2016) are also shown in the figure for comparison.

The relation of depth-area of the Tai Mo Shan 4-hour PMP in this study is given in Table 8.1.

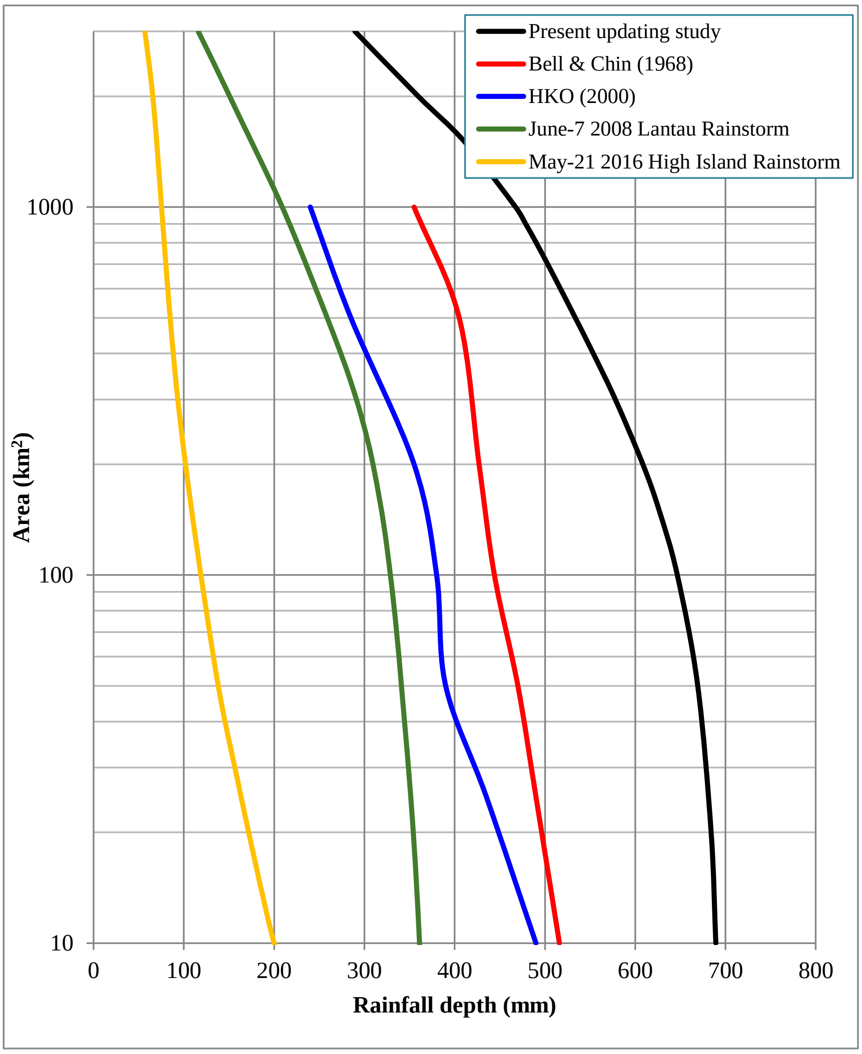


**Figure 8.1 DAD Curves of Updated 4-hour PMP for Application**

Based on Section 7.6, the centre point value of the Tai Mo Shan PMP is 718.2 mm. Nonetheless, in view of the uncertainties associated to the estimate of rainfall in an area smaller than 10 km$^2$, it is recommended to adopt the value corresponding to 10 km$^2$ as the updated PMP which is equal to 689.3 mm as shown in Figure 8.1.

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**Table 8.1 Relation of Depth-Area Updated 4-hour PMP for Application**

| Area ($km^2$) | Depth (mm) |
|---|---|
| 10 | 689.3 |
| 20 | 684.1 |
| 50 | 669.2 |
| 100 | 646.6 |
| 150 | 626.5 |
| 200 | 608.4 |
| 300 | 578.0 |
| 400 | 553.5 |
| 500 | 533.6 |
| 600 | 517.1 |
| 700 | 502.9 |
| 800 | 490.3 |
| 900 | 478.6 |
| 1000 | 467.4 |
| 1500 | 411.5 |
| 2000 | 359.6 |
| 3000 | 289.6 |

# 9 DAD Analysis

## 9.1 Overview

Depth-Area-Duration (DAD) analysis is one of the well-known international practices for interpreting PMP estimation. DAD curves are developed from spatial mean rainfalls for different durations over several major storms in the study area including local storms and storms in the vicinity. The quality and value of DAD curves depend greatly upon the samples of major storms that were surveyed and investigated. Storm moisture maximisation is sometimes incorporated with DAD analysis in PMP estimation to obtain the local estimates for the worst situation.

In the present study, the top fifteen storms in Hong Kong were surveyed and investigated, as shown in Table 3.5. The Kriging method, which requires a denser network of raingauge stations, was used for spatial interpolation when spatial mean rainfall to a certain area for the local storms was calculated. The sea portion of area was counted together with its land portion to form a complete storm rainfall area in order to represent the realistic and meaningful Depth-Area relation.

## 9.2 Top Fifteen Local Storms in Hong Kong between 1984 and 2015

The corresponding DAD curves of the top fifteen Hong Kong storms between 1984 and 2015 are shown in Appendix G.

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## 9.3 Master DAD without Moisture Maximisation

The Depth-Area relation for 4-hour for the top fifteen storms in Hong Kong is shown in Figure 9.1 and Appendix H.

As shown in Figure 9.1, the 7 June 2008 rainstorm has the highest rainfall depth. This storm had the highest 4-hour rainfall between 1984 and 2015, and it was the fourth most severe 4-hour record measured by HKO HQ between 1885 to 2015. In order to get a master DAD with moisture maximisation, this storm was further analysed as presented in Section 9.4.

Storms of 30 May 1889, 19 July 1926 and 12 June 1966 were the three most severe 4-hour rainstorms recorded at HKO HQ between 1885 to 2015. However, there were no available rainfall data for the development of the DAD curves. Therefore, those storms were discarded. In this study, all the storms used to develop the DAD curves occurred after 1984.

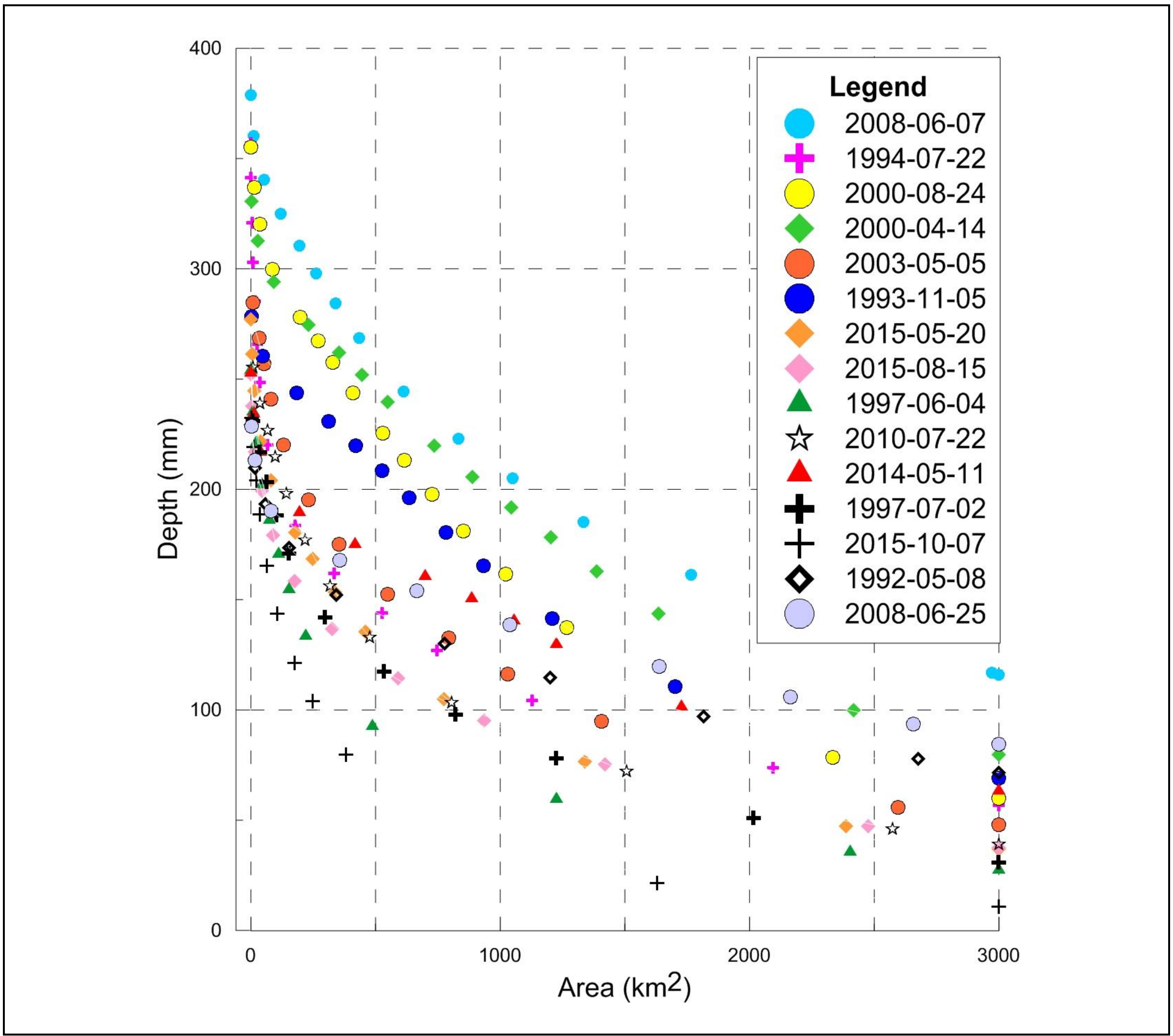


**Figure 9.1 Depth-Area Relation for 4-hour over the Top Fifteen Storms between 1984 and 2015**

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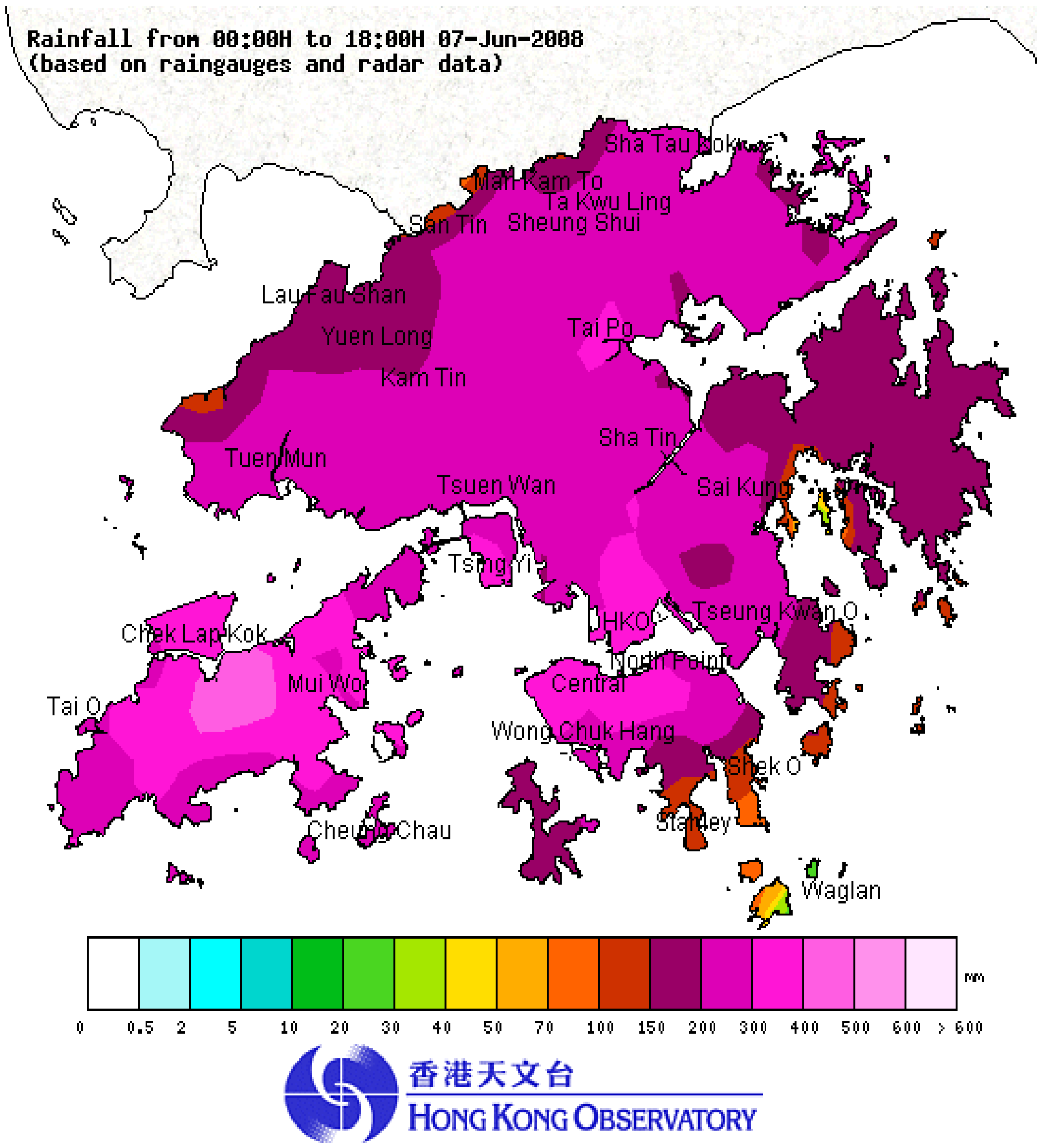
## 9.4 Analysis of the Storm of 7 June 2008

Under the influence of an active trough of low pressure, heavy rain and squally thunderstorms affected Hong Kong on 7 June 2008. The rain was the heaviest in the morning. HKO HQ recorded 145.5 mm during the hour from 8 to 9 a.m., the highest hourly rainfall since record began. From midnight till 6 p.m., 304.8 mm of rain fell at the HKO HQ. About 200 mm of rainfall was recorded generally over Hong Kong, with those at Lantau Island and urban areas exceeding 300 mm. Figure 9.2 shows the rainfall distribution over Hong Kong (from 0:00 to 18:00 on 7 June 2008).




Note: This figure was downloaded from Hong Kong Observatory website.

**Figure 9.2 The Rainfall Distribution in Hong Kong from Midnight to 6 P.M. on 7 June 2008**

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### 9.4.1 The 24-hour and 4-hour Isohyets Chart

Based on the 5-min data and 1-min data of raingauge stations of the GEO and HKO, the maximum 24-hour and 4-hour rainfall of the storm were calculated by 5-min moving window. The maximum 24-hour and 4-hour rainfall isohyets map of the storm are shown in Figures 9.3 and 9.4 respectively.

Besides, a 24-hour rainfall isohyet map of the 7 June 2008 storm (ending at 7 a.m on 7 June 2008) is shown in Figure 9.5 by courtesy of the HKO.

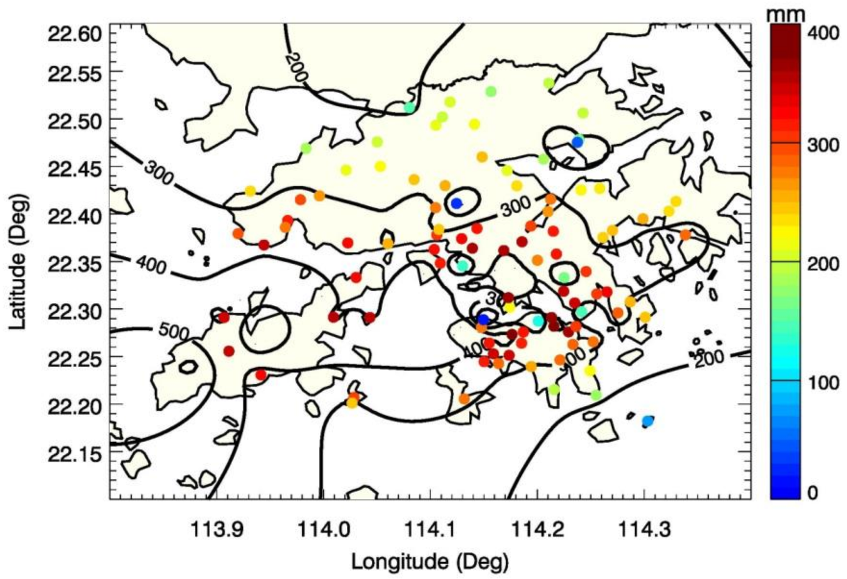


**Figure 9.3 24-hour Rainfall Isohyets Map of 7th June, 2008 Storm**

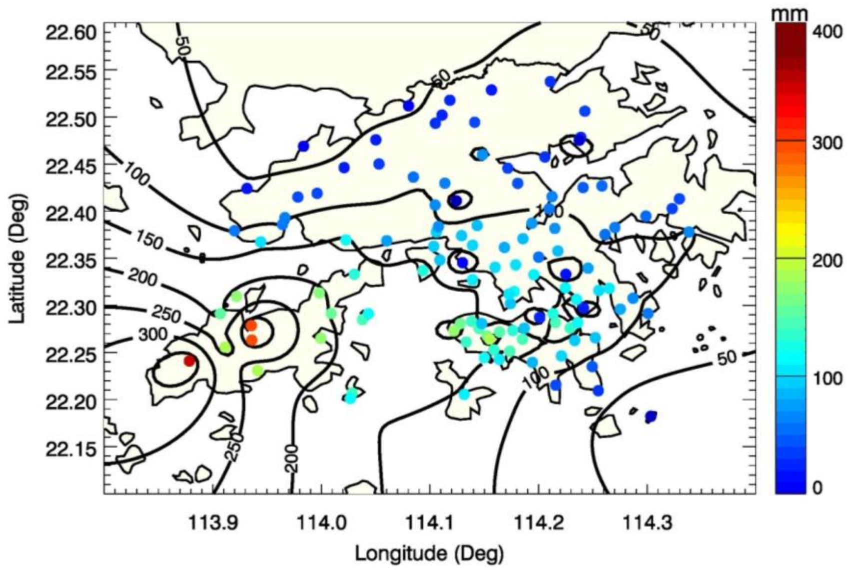


**Figure 9.4 4-hour Rainfall Isohyets Map of 7th June, 2008 Storm**

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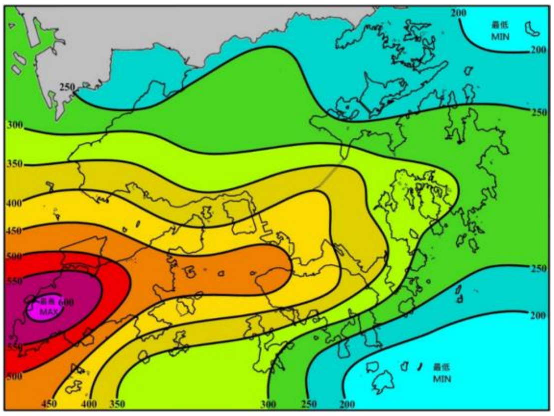

**Figure 9.5 24-hour Rainfall Isohyets Map of 7th June, 2008 Storm (from HKO)**

### 9.4.2 12-hour Maximum Persisting Dew Point

There are 28 raingauge stations with dew point observation in Hong Kong, and the locations of these stations are shown in Figure 9.6. The storm centre of the storm is at N19, where the maximum 4-hour rainfall was 384 mm. According to the hourly data of N19, the time history of hourly rainfall of N19 was plotted in Figure 9.7, which shows that the peak rainfall time of the storm started at 6 a.m. on 7 June 2008. Therefore, the time of the maximum 12-hour persisting dew point should be prior to this time. Combining the direction of moisture flux (Figure 9.8) and the locations of the dew point stations, six stations were chosen as the representative stations. They were CCH, WGL, HKS, HKO, KP, JKB, which were marked in Figure 9.6.

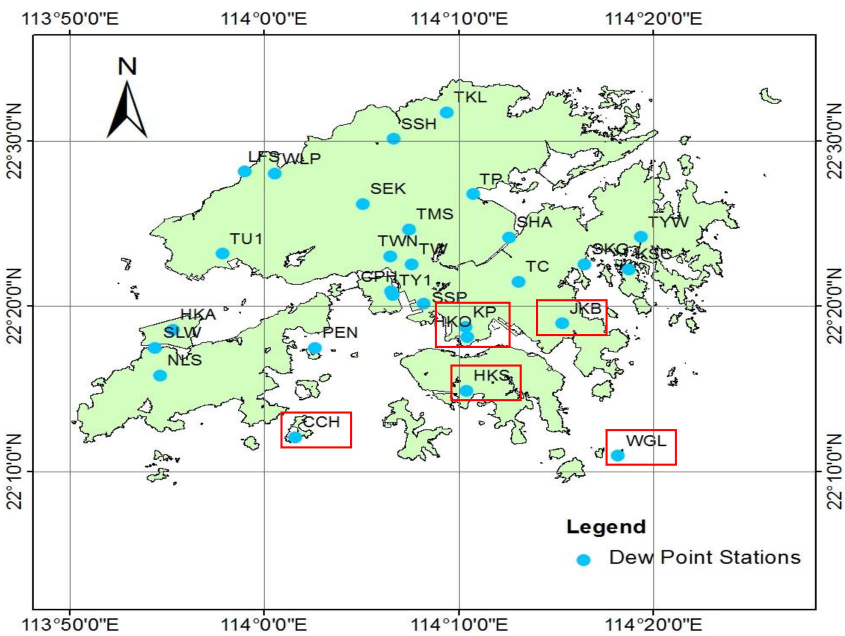


**Figure 9.6 Locations of Dew Point Stations in Hong Kong**

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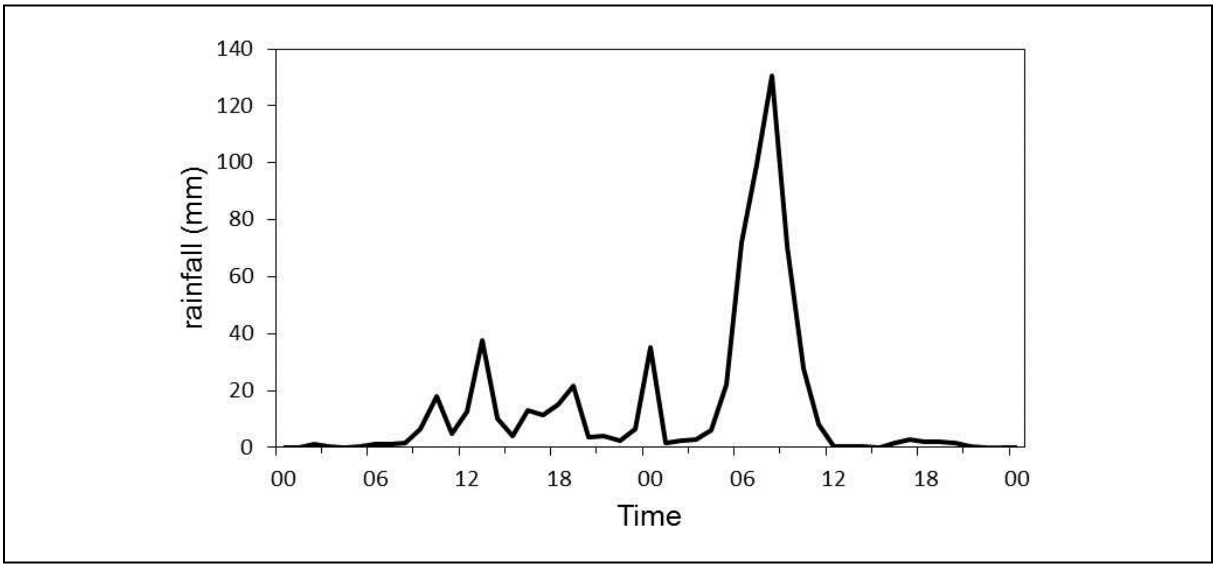


**Figure 9.7 Time History of Hourly Rainfall in 6-7 June 2008 at N19**

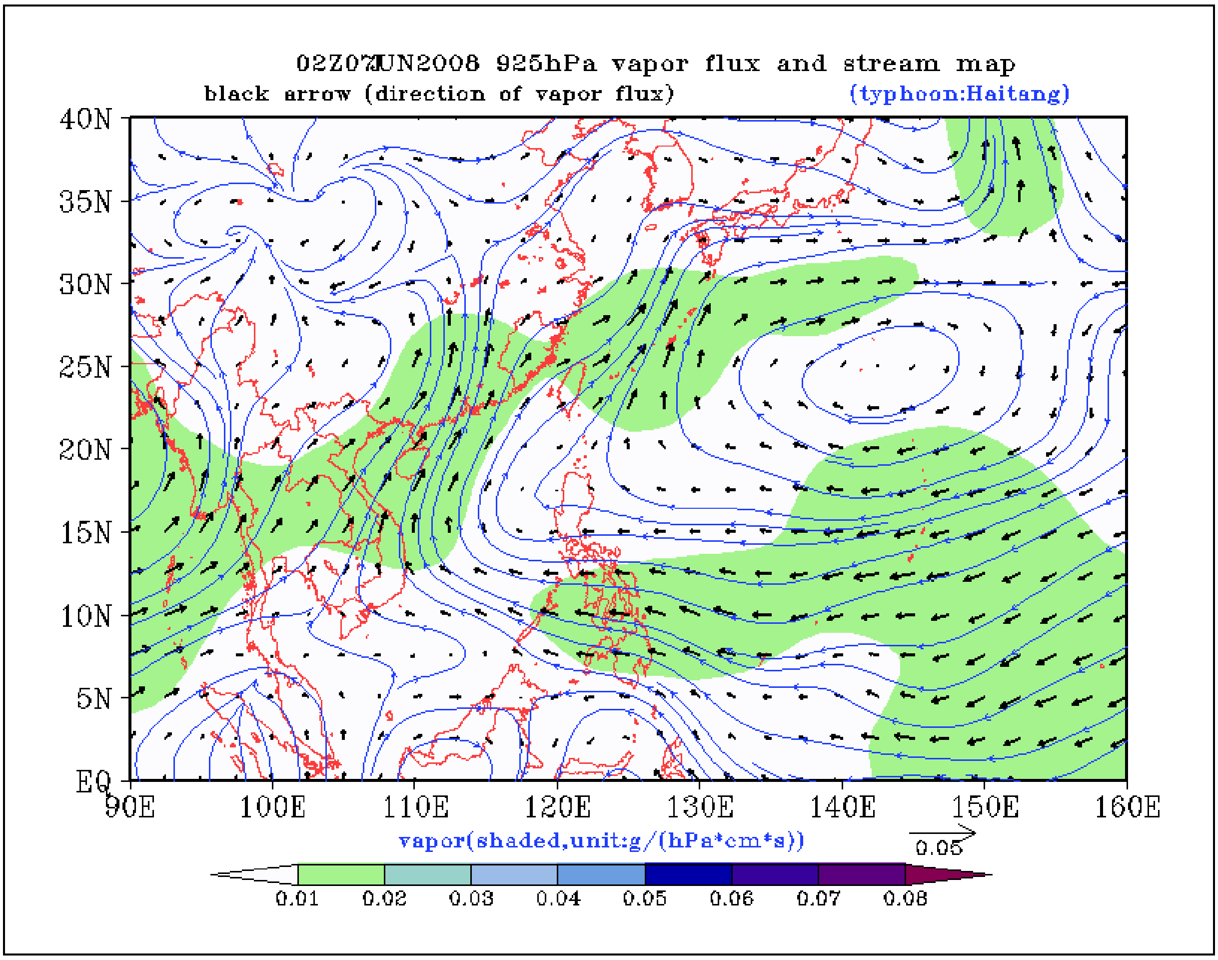


**Figure 9.8 Moisture Flux of the Storm 7 June 2008**

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Table 9.1 lists the 12-hour persisting dew point of representative stations of the storm. The 12-hour persisting dew point was converted to persisting 12-hour 1000-hPa dew point. Therefore, the average persisting 12-hour 1000-hPa dew point was 23.26°C, corresponding to precipitable water of 67.48 mm.

Ratio of moisture maximisation is estimated as follow:

$$r = W_2 / W_1 = 97.12 / 67.48 = 1.44$$

where $W_2$ = adjusted precipitable water for the 100-year return period of the historical maximum 12-hour persisting dew point for the design area of Hong Kong, which is 27.24°C

$W_1$ = adjusted precipitable water for the representative dew point, 23.26°C, for 7 June 2008 storm.

**Table 9.1 12-hour Persisting Dew Point of Representative Station of the Storm at 7 June 2008**

| Name | Abbreviation | Longitude | Latitude | Elevation (m) | Maximum Persisting 12-hour Dew Point (°C) | 12-hour 1000-hPa Storm Dew Points (°C) |
|---|---|---|---|---|---|---|
| Cheung Chau | CCH | 114.02 | 22.20 | 24 | 23.6 | 23.70 |
| Waglan Island | WGL | 114.30 | 22.18 | 27 | 23.3 | 23.41 |
| Wong Chuk Hang | HKS | 114.17 | 22.24 | 5 | 23.0 | 23.02 |
| King's Park | KP | 114.17 | 22.31 | 24 | 23.1 | 23.10 |
| Tseung Kwan O | JKB | 114.25 | 22.31 | 25 | 23.0 | 23.20 |
| Hong Kong Observatory HQ | HKO HQ | 114.17 | 22.30 | 32 | 23.3 | 23.13 |

## 9.5 Master DAD with Moisture Maximisation

The master DAD curve with moisture maximisation for 4-hour rainfall based on the top fifteen Hong Kong storms is shown in Figure 9.9. The details of the above DAD relation are tabulated in Table 9.2[b]. It can be shown that 7 June 2008 is the control case in the whole range of the Master DAD curve.

The storm transposition and DAD analysis are two different approaches and there is no common ground to compare the results of the two methods. Nevertheless, the DAD curve based on transposition of Taiwan storms (i.e. the PMP estimate with centres at Tai Mo Shan) is also plotted in Figure 9.9. It is shown that the results based on storm transposition are generally higher than those based on local DAD analysis.

[b] Normally, the DAD curves are developed based on the local storms with moisture maximization only. Storms in Macau were not selected due to their relatively low rainfall intensity.

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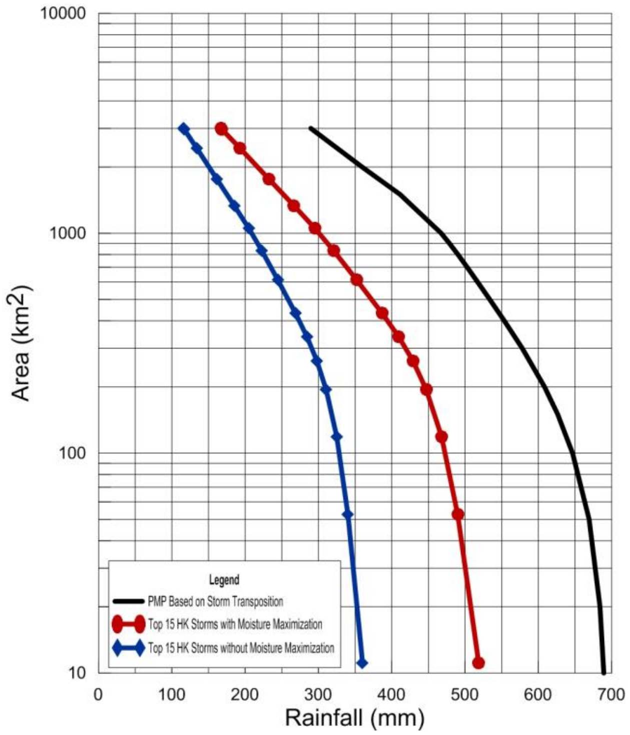


Note: "PMP based on storm transposition" above means the DAD curve of the PMP estimates centred at Tai Mo Shan.

**Figure 9.9 Master DAD Curve with Moisture Maximisation for 4-hour Rainfall**

**Table 9.2 Master DAD Curve with Moisture Maximisation for 4-hour Rainfall Based on the Top Fifteen Hong Kong Storms**

| Area ($km^2$) | Depth (mm) |
|---|---|
| 0.6 | 545.5[1] |
| 11.1 | 518.6[1] |
| 52.5 | 490.0[1] |
| 118.8 | 467.9[1] |
| 194.1 | 447.1[1] |
| 262.5 | 429.0[1] |
| 339.0 | 409.3[1] |
| 433.5 | 386.6[1] |
| 613.8 | 352.0[1] |
| 832.2 | 320.8[1] |
| 1050.6 | 295.3[1] |
| 1335.3 | 266.5[1] |
| 1765.5 | 232.2[1] |
| 2435.1 | 193.0[1] |
| 2972.1 | 168.1[1] |
| 3000.0 | 166.8[1] |

Note: [1] 7 June 2008 storm ($r$ = 1.44).

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# 10 Evaluation of PMP Estimates

## 10.1 General

As pointed out by Mr Marshall E. Hansen, an American meteorologist and a prominent PMP investigator, it is not possible to know what the correct answer is for PMP, only that the estimates represent the best answer that current knowledge and data will support (Hansen, 1987).

## 10.2 Comparison of the PMP Estimates in this Study

In this study, the statistical method, DAD analysis, and the international best practice storm transposition by using storm separation technique based on the SDOIF Method were used to estimate the 4-hour PMP in Hong Kong. The results are shown in Table 10.1. The value of 559.3 mm of the 4-hour PMP estimates by using the modified statistical approach represents the general statistical estimate of the entire Hong Kong territory. The centre point of 4-hour PMP estimate at Tai Mo Shan by using the storm transposition and moisture maximisation is 718.2 mm. The central value of the 4-hour master DAD with moisture maximisation based on the top fifteen storms for the period from 1984 to 2015 is 545.5 mm. It is shown that the results based on storm transposition are higher than those based on local DAD analysis and the statistical method.

**Table 10.1 The 4-hour PMP Results of Hong Kong by Different Estimation Method**

| Estimation Method | 4-hour PMP (mm) |
|---|---|
| Statistical Method | 559.3 |
| Storm Transposition | 718.2 |
| DAD Analysis | 545.5 |

## 10.3 Comparison with Extreme Rainfall Records for Hong Kong, Southeast China Region and the World

Comparisons between the PMP estimate and the rainfall records Hong Kong, the Southeast China region including Zhejiang, Fujian, Guangdong, Guangxi, Hainan and Taiwan, and the world are illustrated in Figure 10.1. It shows that the 4-hour PMP obtained in this study is higher than the extreme rainfall records in Hong Kong and Southeast China to some noticeable extent and lower than the world 4-hour rainfall record (WMO, 2009). The updated 4-hour PMP of Hong Kong based on storm transposition method is higher than the 4-hour rainfall record in Taiwan. Tables 10.2 to 10.5 give the rainfall records used to produce Figure 10.1.

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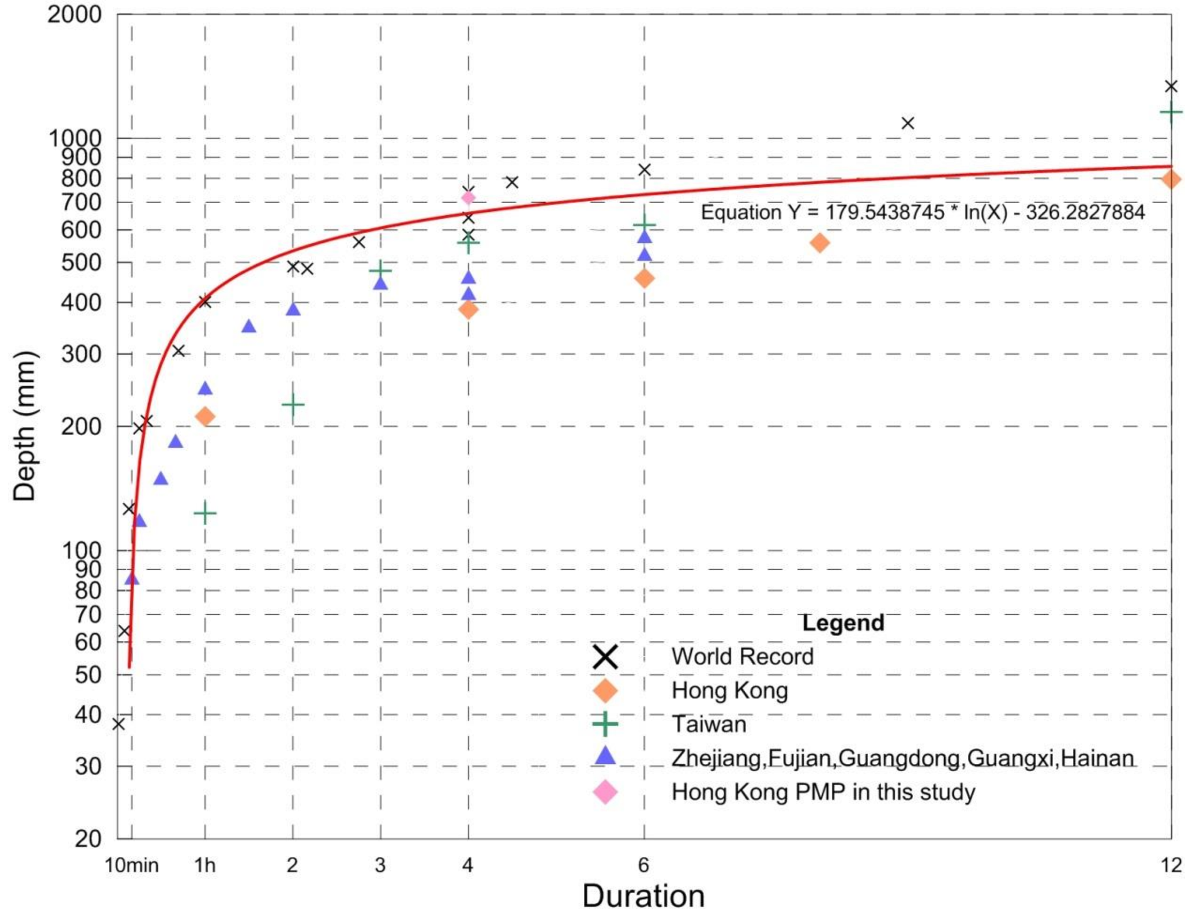


**Figure 10.1 Comparison of Hong Kong PMP Updates with Extreme Rainfall Records in Hong Kong, the Southeast China including Taiwan as well as the World Records**

**Table 10.2 Rainfall Records for Hong Kong**

| Duration | Date | Location | Storm Type | Rainfall (mm) |
|---|---|---|---|---|
| 1-hour | 1994-07-22 | Tai Mo Shan | Trough of low pressure | 211.5 |
| 4-hour | 2008-06-07 | Lantau | Trough of low pressure | 384.0 |
| 6-hour | 1994-07-22 | Tai Mo Shan | Trough of low pressure | 457.5 |
| 8-hour | 1994-07-22 | Tai Mo Shan | Trough of low pressure | 558.0 |
| 12-hour | 1994-07-22 | Tai Mo Shan | Trough of low pressure | 793.5 |

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**Table 10.3 Rainfall Records for Taiwan**

| Duration | Date | Location | Storm | Rainfall (mm) |
|---|---|---|---|---|
| 1-hour | 2009-08-08 | Ahlishan 阿里山 | Morakot | 123.0 |
| 2-hour | 2009-08-08 | Ahlishan 阿里山 | Morakot | 226.0 |
| 3-hour | 2002-07-10 | Pengjiayu 彭佳嶼 | Nakri | 476.0 |
| 4-hour | 2010-10-21 | Suao 蘇澳 | MEGI | 558.5 |
| 6-hour | 1996-07-31 | Ahlishan 阿里山 | Herb | 616.5 |
| 12-hour | 1996-07-31 | Ahlishan 阿里山 | Herb | 1157.5 |

**Table 10.4 Rainfall Records for Zhejiang, Fujian, Guangdong, Guangxi and Hainan**

| Duration | Date | Location | Storm Type | Rainfall (mm) |
|---|---|---|---|---|
| 10-min | 1985-08-24 | Jinkeng, Zengcheng, Guangdong | Front | 84.8 |
| 15-min | 1992-07-04 | Bengshan, Guangze, Fujian | Front | 117.0 |
| 40-min | 1979-06-10 | Dongxikou, Chenghai, Guangdong 東溪口，澄海，廣東 | Front | 182.4 |
| 1-hour | 1979-06-10 | Dongxikou, Chenghai, Guangdong 東溪口，澄海，廣東 | Front | 245.1 |
| 1.5-hour | 1979-06-10 | Dongxikou, Chenghai, Guangdong 東溪口，澄海，廣東 | Front | 347.1 |
| 2-hour | 1979-06-10 | Dongxikou, Chenghai, Guangdong 東溪口，澄海，廣東 | Front | 380.9 |
| 3-hour | 2005-09-03 | Lin'an, Changhua, Zhejiang 臨安，昌化，浙江 | Local convective weather | 441.0 |
| 4-hour | 2010-09-21 | Guangdong 廣東 | Typhoon | 416.5 |
| 4-hour | 2005-09-03 | Lin'an, Changhua, Zhejiang 臨安，昌化，浙江 | Local convective weather | 456.3 |
| 6-hour | 1999-10-09 | Xiazhanglong, Putian, Fujian 下張隆，莆田，福建 | Tropical cyclone | 517.0 |
| 6-hour | 1977-07-20 | Baisha, Hainan | Typhoon | 571.0 |

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**Table 10.5 World Rainfall Records**

| Duration | Date | Location | Rainfall (mm) |
|---|---|---|---|
| 1-min | 1970-11-26 | Barot, Guadeloupe | 38 |
| 5-min | 1972-02-02 | Haynes Canyon, California, United States | 64 |
| 8-min | 1920-05-25 | Fussen, Bavaria | 126 |
| 15-min | 1916-05-12 | Plumb Point, Jamaica | 198 |
| 20-min | 1889-07-07 | Curtea-de-Arges, Romania | 206 |
| 42-min | 1947-06-22 | Holt, Missouri, United States | 305 |
| 1-hour | 1975-07-03 | Chifeng, Nei Monggol, China | 401 |
| 2-hour | 1975-07-19 | Yujiawanzi, Nei Monggol, China | 489 |
| 2-hour 10-min | 1889-07-18 | Rockport, West Virginia, United States | 483 |
| 2-hour 45-min | 1935-05-31 | D’Hanis, Texas, United States | 559 |
| 4-hour | 1880-01-12 | Basseterre, St.Kitts, West Indies | 584 |
| 4-hour | 1975-08-07 | Linzhuang, Henan, China | 642 |
| 4-hour | 1958-08-04 | Shihetou, Shandong, China | 740 |
| 4-hour 30-min | 1889-07-18 | Smethport, Pennnsylvania, United States | 782 |
| 6-hour | 1977-08-01 | Muduocaidang, Nei Monggol, China | 840 |
| 9-hour | 1964-02-28 | Belouve, La Réunion | 1087 |
| 12-hour | 1964-02-28-29 | Belouve, La Réunion | 1340 |

## 10.4 Comparison of Hong Kong 4-hour PMP Updates with Previous Hong Kong PMP Estimates

Storm transposition was not adopted in the previous studies on 4-hour PMP estimates for Hong Kong. The DAD analyses were adopted to obtain the PMP estimates in Hong Kong in previous studies. Therefore, the updated PMP based on DAD analyses is compared with the previous PMP estimates derived from DAD analysis.

Figure 10.2 shows the comparison. Tables 10.6 gives the values of PMP estimates presented in the Figure.

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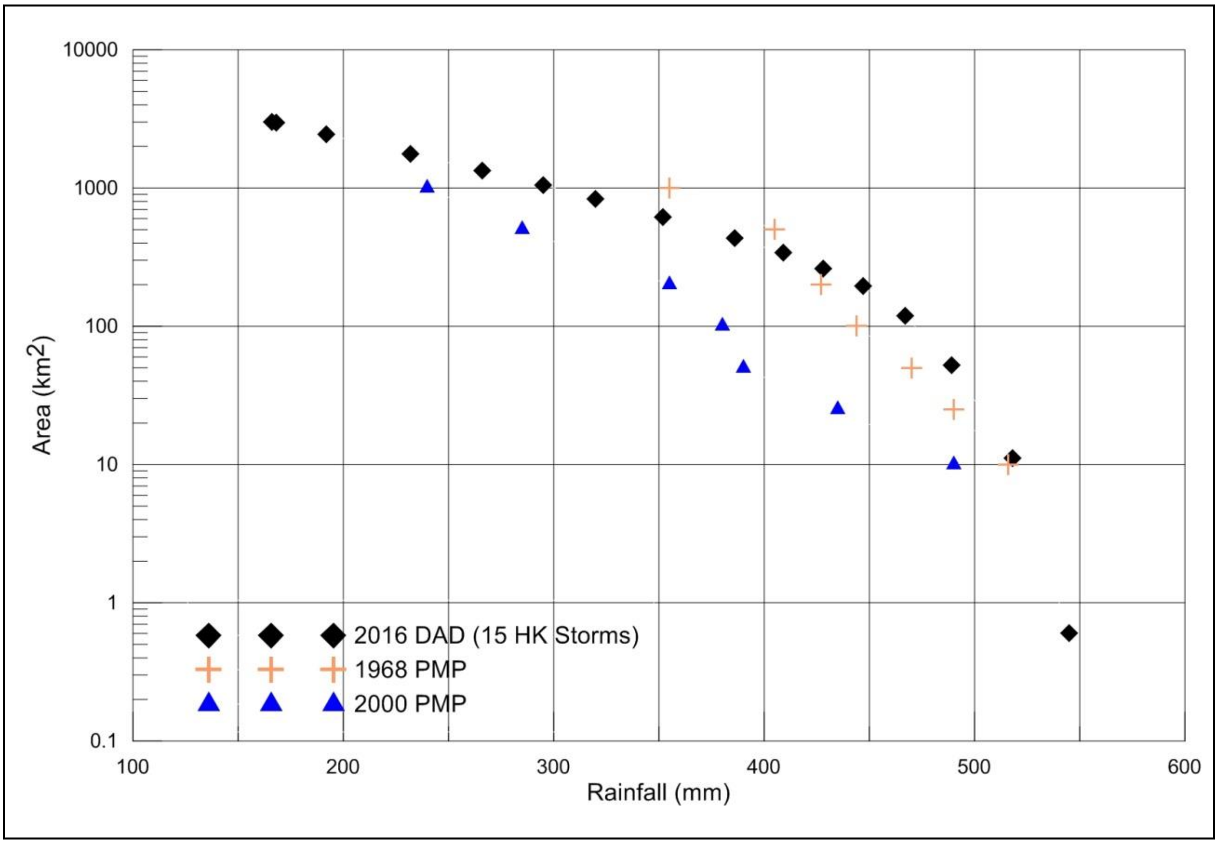


**Figure 10.2 Comparison of 1968 and 2000 PMP with the 2016 Master DAD for 4-hour PMP in Hong Kong**

**Table 10.6 Comparison of 1968 and 2000 PMP with the 2016 Master DAD for 4-hour PMP in Hong Kong (Sheet 1 of 2)**

| Area ($km^2$) | Depth (mm) | | |
|---|---|---|---|
| | 2016 | 1968 | 2000 |
| 0.6 | 545 | - | - |
| 10.0 | - | 516 | 490 |
| 11.1 | 518 | - | - |
| 25.0 | - | 490 | 435 |
| 50.0 | - | 470 | 390 |
| 52.5 | 489 | - | - |
| 100.0 | - | 444 | 380 |
| 118.8 | 467 | - | - |
| 194.1 | 447 | - | - |
| 200.0 | - | 427 | 355 |
| 262.5 | 428 | - | - |
| 339.0 | 409 | - | - |

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**Table 10.6 Comparison of 1968 and 2000 PMP with the 2016 Master DAD for 4-hour PMP in Hong Kong (Sheet 2 of 2)**

| Area (km$^2$) | Depth (mm) | | |
|---|---|---|---|
| | 2016 | 1968 | 2000 |
| 433.5 | 386 | - | - |
| 500.0 | - | 405 | 285 |
| 613.8 | 352 | - | - |
| 832.2 | 320 | - | - |
| 1000.0 | - | 355 | 240 |
| 1050.6 | 295 | - | - |
| 1335.3 | 266 | - | - |
| 1765.5 | 232 | - | - |
| 2435.1 | 192 | - | - |
| 2972.1 | 168 | - | - |
| 3000.0 | 166 | - | - |

Currently, there is no existing 4-hour PMP study used for safety assessment of infrastructures such as hydropower dam or flood protection planning for cities located in the typhoon-prone Southeast China region. The 4-hour is a unique duration for PMP estimation in the Southeast China and anywhere else in China, therefore there is no way to compare the 4-hour PMP estimates with other 4-hour PMP estimates in the Southeast China.

## 10.5 Findings of the Comparison

Figure 10.1 indicates that the PMP update by using storm transposition approach is higher than the extreme rainfall records in Hong Kong to some noticeable extent and higher than the rainfall records in Southeast China and Taiwan, and very close to the envelop of the world records for the centre point value when the generalised convergence component pattern is superposed on Hong Kong centred at Tai Mo Shan. This is reasonable and supported by the best knowledge and up-to-date data.

Figure 10.2 indicates that the update 4-hour PMP estimates by using DAD approach are very close to or slightly higher than the 1968 4-hour PMP estimates and 2000 4-hour PMP estimates as all studies employed the same local storms with some new storms used for this study.

The current 4-hour Hong Kong PMP updates are reasonable and reliable with support by the updated data and the technique developed based on all the four techniques, namely statistical method approach, storm transposition, DAD analysis and moisture maximisation, which are the most common international practices for PMP estimation.

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## 11 Conclusions

The previous 4-hour PMP updated study covered local storms up to year 2000 while several severe storms have occurred in Hong Kong and Southeast China since 2000. There is a need for updating the 4-hour PMP using an improved PMP estimation technique recommended in the 3rd Edition of Manual on Estimation of PMP published by WMO (2009).

In this study, the international best practices were adopted by considering non-local storms in meteorologically similar area using storm transposition method. Distinguishing from the previous 4-hour PMP study, storm separation technique based on the SDOIF Method was applied to separate orographic effect from rainfall data for non-local storms. The transposed convergence component from Taiwan was combined with the local orographic factors to estimate a new 4-hour PMP in Hong Kong.

The storm transposition analysis based on Typhoon Kalmaegi, Herb, Morakot and Fanapi was undertaken. The updated 4-hour PMP corresponding to a rainfall area of 10 $km^2$ is 689.3 mm. In view of the uncertainties involved in the estimation of PMP at a rainfall area smaller than 10 $km^2$, the worst scenario developed from the above PMP estimate of 689.3 mm is adopted as the 4-hour PMP value in Hong Kong.

Updating of PMP is suggested in the future if other severe storms with extreme rainfall occurred. To facilitate future updating study, keeping track of extreme rainfall events in meteorologically similar areas is recommended.

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# Appendix A

## Storms Investigated in Southeast of China

**Table A1 Top Twenty Short Duration Rainfall Events in Southeast of Mainland China (Sheet 1 of 2)**

| No. | Province | Location | Storm Type | Rainfall (mm) | | | | | | Data |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 15 min | 1 hour | 2.5 hour | 3 hour | 4 hour | 6 hour | |
| 1 | Guangdong | Huidong Gaotan | Typhoon Utor and SW monsoon | | | | 280 | | | 13 Aug 2013 |
| 2 | Guangdong | Qingyuan | Stationary front and trough | | | | | | 542 | 12 May 1982 |
| 3 | Guangdong | Zhuxiandong | | | | | 370 | | | 1996 |
| 4 | Guangdong | Gangkou | | | | | 287 | | | 1995 |
| 5 | Guangdong | Tangkouyu | | | | | | 366 | | 13 May 1979 |
| 6 | Guangdong | Shenyong | | | | | | 360 | | 14 May 1979 |
| 7 | Guangdong | Xingfu farm | Typhoon Pabuk | | | | | 396.2 | | 10 Aug 2007 |
| 8 | Guangdong | Shuangpei | | | | | | 347 | | 21 May 1987 |
| 9 | Guangdong | Shangmaoping | Typhoon Fanapi | | | | | 416 | | 21 Sep 2010 |
| 10 | Fujian | Dehuashuanghan gongshe | | | | 350 | | | | 04 Jun 1977 |
| 11 | Fujian | Fu’an Gantang | | | | 300~400 | | | | 02 Sep 1979 |
| 12 | Fujian | Guangze Bengshan | Convectional rain | 117 | | | 277 | | 439 | 04 Jul 1992 |
| 13 | Fujian | Putian Xiazhanglong [1] | #9914 Typhoon | 51 | 105 | 337 | 390 | 438 | 517 | 09 Oct 1999 |
| 14 | Guangxi | Qinzhou wuzhai | Southwest warm and humid air and weak cold air | | 173 | | 339 | | | 05 Jun 2005 |
| 15 | Guangxi | Qinzhou Dongxing | | | | | 335 | | | 16 May 1972 |
| 16 | Guangxi | Qinzhou Hanxiang | | | | | 315 | | | 28 Jun 1988 |
| 17 | Guangxi | Zailao | Low-level jet | | | | | | 486.1 | 15 Jul 1996 |

**Table A1 20 Short Time Storms in Southeast of Mainland China (Sheet 2 of 2)**

| No. | Province | Location | Storm Type | Rainfall (mm) | | | | | | Data |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 15 min | 1 hour | 2.5 hour | 3 hour | 4 hour | 6 hour | |
| 18 | Zhejiang | Wenzhou | #9909 tropic cyclone | | | | 322.8 | | | 04 Sep 1999 |
| | Zhejiang | Wenzhou | | | 138 | | 347 | | | 04 Sep 1999 |
| 19 | Zhejiang | Lin'an Changhua | Local convective weather | | | | 441 (2) | 456.3 | | 03 Sep 2005 |
| 20 | Hainan | Baisha | #7703 Typhoon | | | | 282 | | 571 | 20 Jul 1977 |

Notes:
(1) The 438 mm-4-hour at Xiazhanglong in Putian County of Fujian, caused by #9914 Typhoon was considered for storm separation method to get its convergence rain in this Study.
(2) The 441 mm / 4-hour was checked based on the minute data of Changhua raingauge station provided by Hangzhou Hydrology and Water Resources Monitoring Station, and it is confirmed to be correct. It was caused by a strong local convective storm within a very small area without major consequences, with no more rainfall information in the vicinity provided and is of less value in consideration for transposition. The 4-hour maximum rainfall of the storm at this location was 456.3 mm.



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# Appendix B

## Results of Statistical Method for 4-hour PMP

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| No. | ID | n(Yr) | $X_m$ (mm) | $\bar{X}_n$ (mm) | $\bar{X}_{n-1}$ (mm) | $S_n$ | $S_{n-1}$ | $\phi_m=(X_m-\bar{X}_n)/S_n$ | $\phi^2_m+2$ | $C_{vn}$ | $\bar{X}'_n=(1+3C_{vn}/\sqrt{n})*\bar{X}_n$ | $K_m=(X_m-\bar{X}_{n-1})/S_{n-1}$ | $n\geq(\phi^2_m+2)$ | $N_s\geq5.76(\phi^2_m+2)$ | When $K_m\rightarrow\phi_m$, required $n_s\leq3.5n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | N14 | 32 | 349 | 150.3 | 143.94 | 61.2 | 50.1 | 3.246 | 12.53 | 0.41 | 182.804 | 4.09 | Ok | 72 | Ok |
| 2 | N17 | 25 | 347 | 145.2 | 136.75 | 61.4 | 45.7 | 3.286 | 12.8 | 0.42 | 182.009 | 4.598 | Ok | 74 | Ok |
| 3 | ~~R14~~ | ~~31~~ | ~~329.5~~ | ~~106.4~~ | ~~98.95~~ | ~~52.4~~ | ~~32.7~~ | ~~4.255~~ | ~~20.11~~ | ~~0.49~~ | ~~134.637~~ | ~~7.048~~ | ~~Ok~~ | ~~116~~ | ~~NO~~ |
| 4 | ~~H21~~ | ~~30~~ | ~~318.5~~ | ~~114.9~~ | ~~107.83~~ | ~~50.2~~ | ~~32.9~~ | ~~4.054~~ | ~~18.44~~ | ~~0.44~~ | ~~142.365~~ | ~~6.407~~ | ~~Ok~~ | ~~106~~ | ~~NO~~ |
| 5 | HKO | 125 | 302.3 | 125.5 | 124.07 | 48.3 | 45.8 | 3.659 | 15.39 | 0.39 | 138.463 | 3.892 | Ok | 89 | Ok |
| 6 | H01 | 31 | 296 | 128.1 | 122.53 | 52.9 | 43.5 | 3.171 | 12.06 | 0.41 | 156.652 | 3.985 | Ok | 69 | Ok |
| 7 | H02 | 32 | 286.5 | 126.6 | 121.47 | 48.7 | 39.6 | 3.283 | 12.78 | 0.39 | 152.454 | 4.163 | Ok | 74 | Ok |
| 8 | sek | 19 | 282.5 | 122 | 113.08 | 52.6 | 36.5 | 3.051 | 11.31 | 0.43 | 158.202 | 4.645 | Ok | 65 | Ok |
| 9 | R11 | 28 | 273.5 | 112.8 | 106.8 | 47.8 | 36.6 | 3.366 | 13.33 | 0.42 | 139.827 | 4.557 | Ok | 77 | Ok |
| 10 | N11 | 32 | 273 | 121.8 | 116.87 | 42.4 | 32.7 | 3.57 | 14.75 | 0.35 | 144.217 | 4.779 | Ok | 85 | Ok |
| 11 | H08 | 32 | 269.5 | 127.2 | 122.63 | 47.7 | 40.6 | 2.986 | 10.92 | 0.38 | 152.489 | 3.616 | Ok | 63 | Ok |
| 12 | H04 | 32 | 267 | 130.4 | 126.03 | 50.5 | 44.6 | 2.705 | 9.317 | 0.39 | 157.212 | 3.158 | Ok | 54 | Ok |
| 13 | H10 | 32 | 265 | 126.4 | 121.95 | 48.8 | 42.4 | 2.839 | 10.06 | 0.39 | 152.308 | 3.371 | Ok | 58 | Ok |
| 14 | H16 | 32 | 265 | 131.1 | 126.76 | 51.8 | 46.4 | 2.586 | 8.687 | 0.4 | 158.543 | 2.978 | Ok | 50 | Ok |
| 15 | N05 | 32 | 263.5 | 110.6 | 105.69 | 48.6 | 40.5 | 3.143 | 11.88 | 0.44 | 136.423 | 3.895 | Ok | 68 | Ok |
| 16 | N04 | 32 | 259.5 | 121.4 | 116.92 | 42.1 | 34.2 | 3.284 | 12.78 | 0.35 | 143.682 | 4.165 | Ok | 74 | Ok |
| 17 | K01 | 32 | 258 | 124.6 | 120.32 | 48.2 | 42.2 | 2.77 | 9.671 | 0.39 | 150.164 | 3.259 | Ok | 56 | Ok |
| 18 | R21 | 31 | 257 | 115 | 110.32 | 51.6 | 45.1 | 2.753 | 9.577 | 0.45 | 142.835 | 3.253 | Ok | 55 | Ok |
| 19 | H17 | 32 | 254.5 | 124.8 | 120.65 | 49.7 | 44.4 | 2.608 | 8.804 | 0.4 | 151.193 | 3.012 | Ok | 51 | Ok |
| 20 | N12 | 32 | 252.5 | 111.5 | 106.98 | 44.5 | 36.9 | 3.168 | 12.04 | 0.4 | 135.131 | 3.942 | Ok | 69 | Ok |
| 21 | K06 | 32 | 250 | 131.2 | 127.34 | 52.8 | 49 | 2.249 | 7.057 | 0.4 | 159.196 | 2.504 | Ok | 41 | Ok |
| 22 | N01 | 32 | 247 | 140.3 | 136.82 | 50 | 46.8 | 2.133 | 6.551 | 0.36 | 166.8 | 2.352 | Ok | 38 | Ok |
| 23 | N06 | 32 | 245.5 | 135.4 | 131.81 | 46.7 | 42.9 | 2.357 | 7.556 | 0.35 | 160.14 | 2.651 | Ok | 44 | Ok |
| 24 | K02 | 32 | 244.5 | 131.5 | 127.87 | 45.6 | 41.4 | 2.477 | 8.134 | 0.35 | 155.709 | 2.819 | Ok | 47 | Ok |
| 25 | N09 | 32 | 244.5 | 134.1 | 130.57 | 40.7 | 35.9 | 2.714 | 9.364 | 0.3 | 155.695 | 3.172 | Ok | 54 | Ok |
| 26 | H03 | 32 | 243.5 | 121.3 | 117.32 | 50 | 45.5 | 2.446 | 7.983 | 0.41 | 147.768 | 2.776 | Ok | 46 | Ok |
| 27 | H06 | 32 | 240 | 127.8 | 124.16 | 45.3 | 41 | 2.48 | 8.149 | 0.35 | 151.781 | 2.824 | Ok | 47 | Ok |
| 28 | kp. | 24 | 237 | 116.3 | 111.04 | 44.2 | 36.8 | 2.731 | 9.458 | 0.38 | 143.356 | 3.426 | Ok | 54 | Ok |
| 29 | N18 | 25 | 234 | 137.3 | 133.31 | 50.7 | 47.6 | 1.905 | 5.628 | 0.37 | 167.787 | 2.116 | Ok | 32 | Ok |
| 30 | H18 | 32 | 230.5 | 128.3 | 125.03 | 36.3 | 31.7 | 2.811 | 9.904 | 0.28 | 147.601 | 3.326 | Ok | 57 | Ok |
| 31 | R12 | 31 | 230.5 | 109.7 | 105.65 | 46.1 | 41 | 2.62 | 8.862 | 0.42 | 134.529 | 3.046 | Ok | 51 | Ok |
| 32 | N10 | 32 | 230 | 117.4 | 113.77 | 43.1 | 38.5 | 2.615 | 8.84 | 0.37 | 140.238 | 3.022 | Ok | 51 | Ok |
| 33 | R27 | 31 | 230 | 101.8 | 97.517 | 46.1 | 40.2 | 2.78 | 9.73 | 0.45 | 126.637 | 3.298 | Ok | 56 | Ok |
| 34 | N02 | 32 | 229.5 | 133.2 | 130.05 | 44.3 | 41.3 | 2.177 | 6.739 | 0.33 | 156.627 | 2.409 | Ok | 39 | Ok |
| 35 | sha | 31 | 226.5 | 120.4 | 116.9 | 40.1 | 35.5 | 2.646 | 9.004 | 0.33 | 142.03 | 3.087 | Ok | 52 | Ok |
| 36 | H05 | 32 | 225.5 | 127.4 | 124.21 | 45.9 | 43 | 2.138 | 6.571 | 0.36 | 151.714 | 2.358 | Ok | 38 | Ok |
| 37 | H14 | 32 | 223.5 | 123.8 | 120.58 | 43.6 | 40.3 | 2.286 | 7.227 | 0.35 | 146.924 | 2.555 | Ok | 42 | Ok |
| 38 | N07 | 32 | 222 | 111.8 | 108.24 | 51 | 47.7 | 2.16 | 6.664 | 0.46 | 138.86 | 2.386 | Ok | 38 | Ok |
| 39 | H19 | 32 | 221 | 123 | 119.79 | 41.3 | 37.9 | 2.372 | 7.625 | 0.34 | 144.876 | 2.672 | Ok | 44 | Ok |
| 40 | N13 | 32 | 221 | 131.9 | 128.98 | 45.3 | 42.9 | 1.969 | 5.878 | 0.34 | 155.866 | 2.143 | Ok | 34 | Ok |
| 41 | H15 | 32 | 219 | 115.1 | 111.73 | 37.5 | 32.8 | 2.774 | 9.693 | 0.33 | 134.948 | 3.266 | Ok | 56 | Ok |
| 42 | R19 | 23 | 219 | 120.4 | 115.96 | 34.4 | 27.5 | 2.868 | 10.22 | 0.29 | 141.936 | 3.753 | Ok | 59 | Ok |
| 43 | N15 | 32 | 218.5 | 123.5 | 120.4 | 32.6 | 28.1 | 2.915 | 10.5 | 0.26 | 140.758 | 3.496 | Ok | 60 | Ok |
| 44 | N03 | 32 | 218 | 129.9 | 127.08 | 44.1 | 41.7 | 1.999 | 5.995 | 0.34 | 153.291 | 2.18 | Ok | 35 | Ok |
| 45 | R23 | 31 | 217 | 123.7 | 120.58 | 43.8 | 40.9 | 2.132 | 6.543 | 0.35 | 147.28 | 2.358 | Ok | 38 | Ok |
| 46 | R22 | 31 | 216 | 94.95 | 90.917 | 39.1 | 32.5 | 3.098 | 11.6 | 0.41 | 116.005 | 3.847 | Ok | 67 | Ok |
| 47 | H12 | 32 | 214 | 124.5 | 121.6 | 38.4 | 35.3 | 2.332 | 7.438 | 0.31 | 144.841 | 2.617 | Ok | 43 | Ok |
| 48 | H09 | 32 | 213.5 | 124.9 | 122 | 36.8 | 33.6 | 2.408 | 7.8 | 0.3 | 144.379 | 2.723 | Ok | 45 | Ok |
| 49 | R28 | 31 | 213.5 | 100.9 | 97.117 | 50.9 | 47.2 | 2.215 | 6.904 | 0.5 | 128.275 | 2.468 | Ok | 40 | Ok |
| 50 | H07 | 31 | 211.5 | 115.6 | 112.38 | 39.3 | 35.7 | 2.438 | 7.946 | 0.34 | 136.777 | 2.778 | Ok | 46 | Ok |
| 51 | K07 | 32 | 211 | 130 | 127.4 | 41.2 | 39.1 | 1.966 | 5.866 | 0.32 | 151.86 | 2.139 | Ok | 34 | Ok |
| 52 | slw | 23 | 211 | 115.9 | 111.59 | 44.2 | 40 | 2.15 | 6.624 | 0.38 | 143.573 | 2.487 | Ok | 38 | Ok |
| 53 | K03 | 32 | 207.5 | 115.8 | 112.79 | 39.6 | 36.4 | 2.319 | 7.378 | 0.34 | 136.732 | 2.599 | Ok | 42 | Ok |
| 54 | K08 | 32 | 207.5 | 119.9 | 117.08 | 43.7 | 41.4 | 2.003 | 6.011 | 0.37 | 143.1 | 2.185 | Ok | 35 | Ok |
| 55 | tyw | 21 | 204 | 114.3 | 109.83 | 34.8 | 28.8 | 2.578 | 8.648 | 0.3 | 137.081 | 3.271 | Ok | 50 | Ok |
| 56 | N16 | 30 | 202 | 121.4 | 118.6 | 37.3 | 34.6 | 2.162 | 6.673 | 0.31 | 141.81 | 2.407 | Ok | 38 | Ok |
| 57 | tms | 19 | 201 | 108.1 | 102.92 | 41.1 | 35.4 | 2.26 | 7.109 | 0.38 | 136.374 | 2.77 | Ok | 41 | Ok |
| 58 | N08 | 32 | 200 | 118.9 | 116.24 | 33.6 | 30.7 | 2.414 | 7.83 | 0.28 | 136.682 | 2.731 | Ok | 45 | Ok |
| 59 | tkl | 28 | 199 | 105.9 | 102.41 | 39.2 | 35.4 | 2.375 | 7.639 | 0.37 | 128.094 | 2.73 | Ok | 44 | Ok |
| 60 | K05 | 32 | 197.5 | 120.2 | 117.71 | 38.6 | 36.5 | 2.003 | 6.013 | 0.32 | 140.667 | 2.185 | Ok | 35 | Ok |
| 61 | H20 | 32 | 197 | 120 | 117.57 | 42.8 | 41.1 | 1.8 | 5.239 | 0.36 | 142.724 | 1.935 | Ok | 30 | Ok |
| 62 | lfs | 31 | 196 | 90 | 86.467 | 39.5 | 34.9 | 2.682 | 9.194 | 0.44 | 111.294 | 3.142 | Ok | 53 | Ok |
| 63 | R24 | 31 | 194 | 112.9 | 110.17 | 36.1 | 33.4 | 2.247 | 7.05 | 0.32 | 132.323 | 2.512 | Ok | 41 | Ok |
| 64 | tap | 23 | 190.5 | 103.1 | 99.136 | 41.1 | 37.3 | 2.126 | 6.519 | 0.4 | 128.825 | 2.45 | Ok | 38 | Ok |
| 65 | jkb | 25 | 186 | 111.3 | 108.21 | 35.6 | 32.7 | 2.1 | 6.408 | 0.32 | 132.662 | 2.381 | Ok | 37 | Ok |
| 66 | R18 | 31 | 183.5 | 99.16 | 96.35 | 34.2 | 31 | 2.463 | 8.065 | 0.35 | 117.613 | 2.813 | Ok | 46 | Ok |
| 67 | K04 | 32 | 181 | 123.4 | 121.52 | 33.2 | 32.1 | 1.734 | 5.006 | 0.27 | 141.002 | 1.856 | Ok | 29 | Ok |
| 68 | tc. | 18 | 179 | 110.9 | 106.88 | 30.7 | 26.3 | 2.219 | 6.925 | 0.28 | 132.59 | 2.738 | Ok | 40 | Ok |
| 69 | epc | 23 | 178.5 | 82.94 | 78.591 | 32.1 | 25.1 | 2.973 | 10.84 | 0.39 | 103.042 | 3.987 | Ok | 62 | Ok |
| 70 | cch | 24 | 177 | 103.1 | 99.935 | 35.5 | 32.5 | 2.082 | 6.334 | 0.34 | 124.87 | 2.37 | Ok | 36 | Ok |
| 71 | plc | 23 | 176.5 | 96.41 | 92.773 | 40.4 | 37.3 | 1.98 | 5.921 | 0.42 | 121.713 | 2.242 | Ok | 34 | Ok |
| 72 | R29 | 31 | 175.5 | 92.63 | 89.867 | 31.1 | 27.4 | 2.669 | 9.122 | 0.34 | 109.361 | 3.121 | Ok | 53 | Ok |
| 73 | R31 | 31 | 172.5 | 100.2 | 97.75 | 33.4 | 31.2 | 2.163 | 6.679 | 0.33 | 118.181 | 2.399 | Ok | 38 | Ok |
| 74 | R25 | 31 | 156.5 | 104.3 | 102.58 | 30.7 | 29.6 | 1.7 | 4.891 | 0.29 | 120.857 | 1.821 | Ok | 28 | Ok |
| 75 | wgl | 27 | 126 | 75.98 | 74.058 | 26.8 | 25.3 | 1.869 | 5.491 | 0.35 | 91.437 | 2.051 | Ok | 32 | Ok |
| Max. | | | | | | | | | | 0.43 | 182.804 | 4.779 | | | |

*Out: Check the required stable size Ns and then take some stations out when Ns > 3.5 n as it may cause 50% in error in terms of Km.

最大值

| | |
|---|---|
| $K_m$ | 4.78 |
| $\bar{X}'_n$ | 183 |
| $C_{vn}$ | 0.43 |

4-hour PMP:Xpmp=(1+Km*CVn)*Xn=559.33mm

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# Appendix C

## A Complete Set of Orientation of Convergence Pattern over Hong Kong 4-hour OIF Pattern

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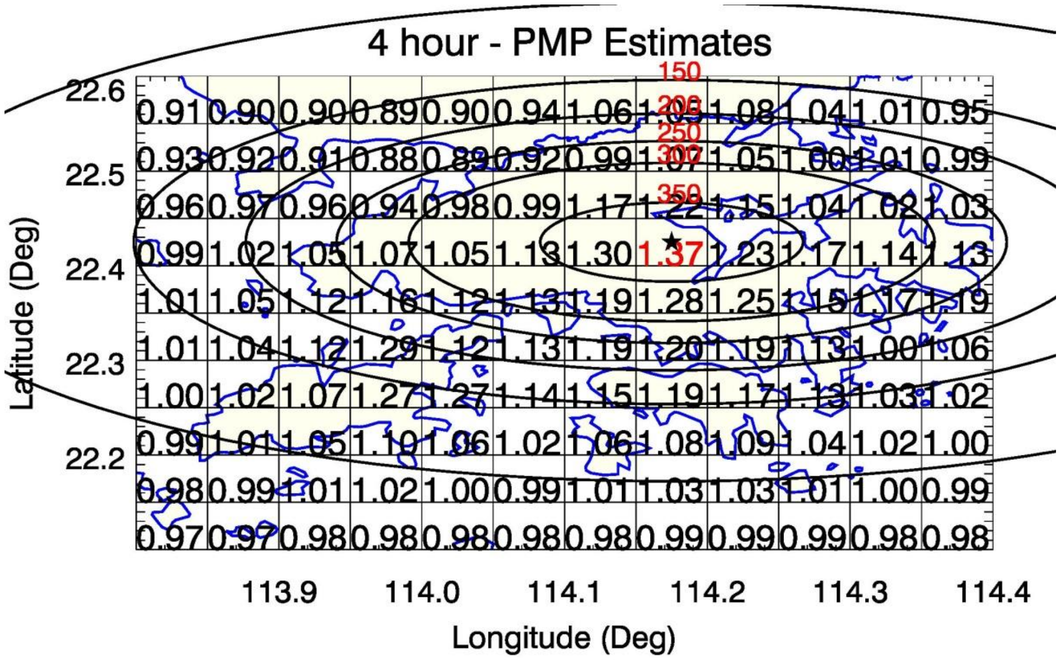
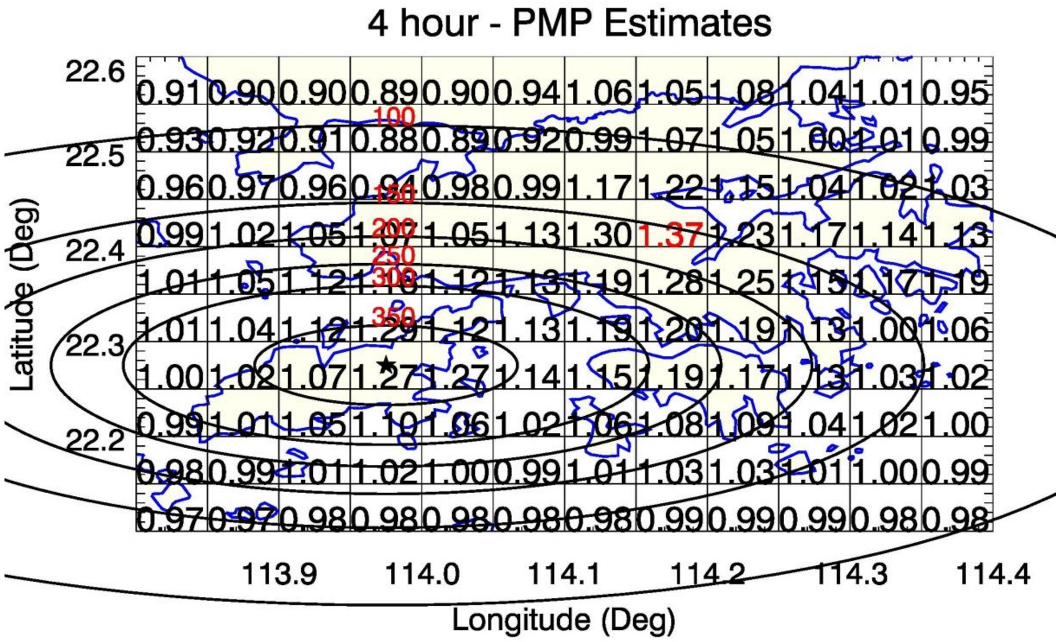



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C1 E-W Orientation 0° (Embryonic PMP)**

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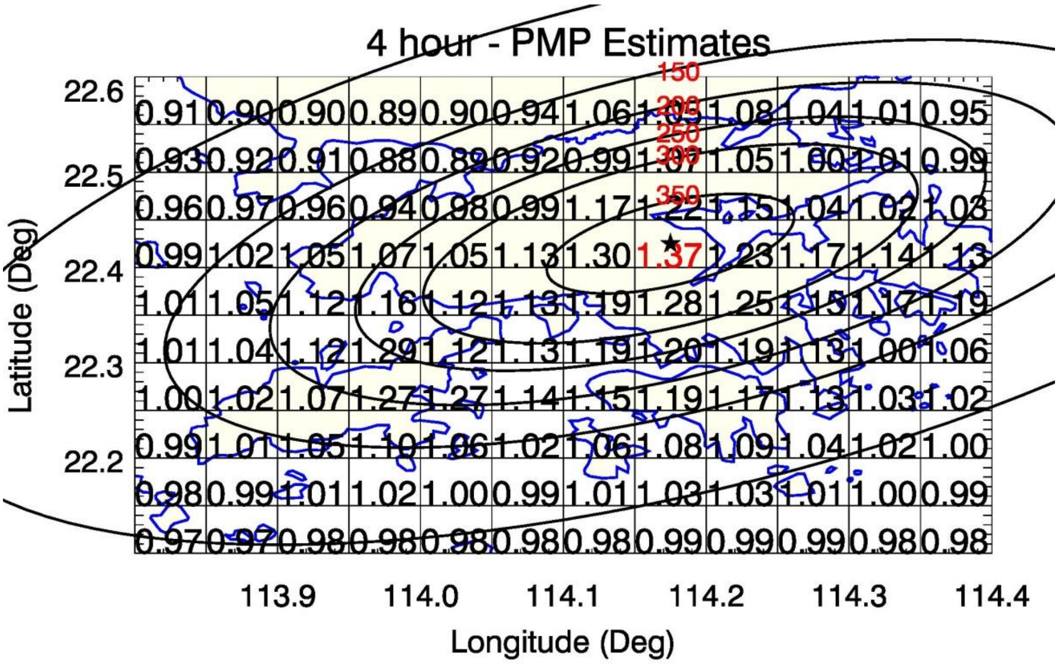
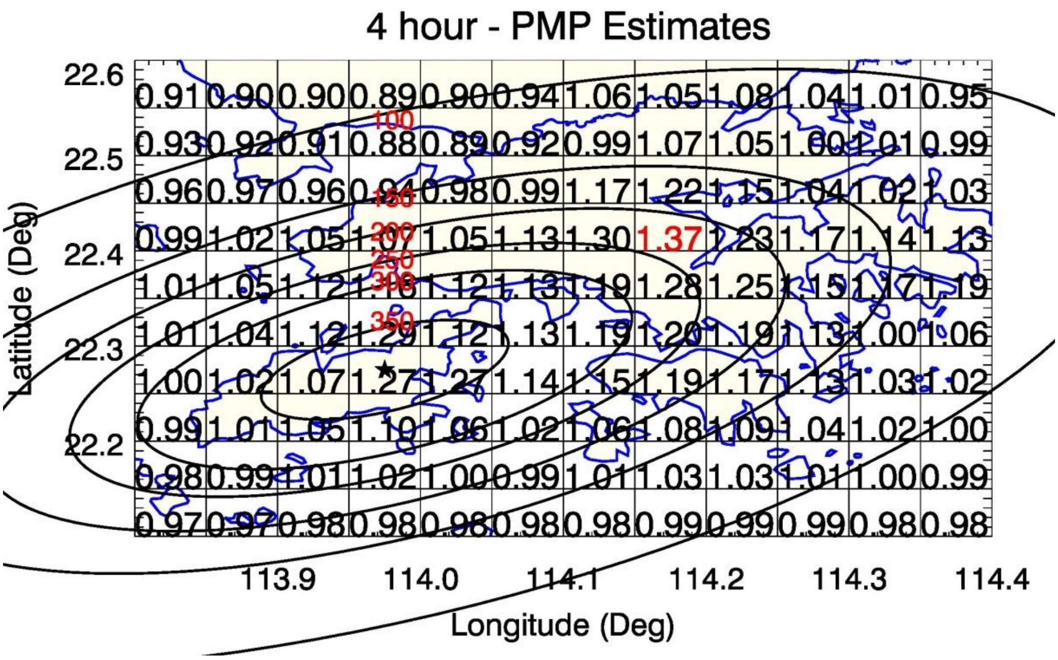



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C2 ENE-WSW Orientation 22.5° (Embryonic PMP)**

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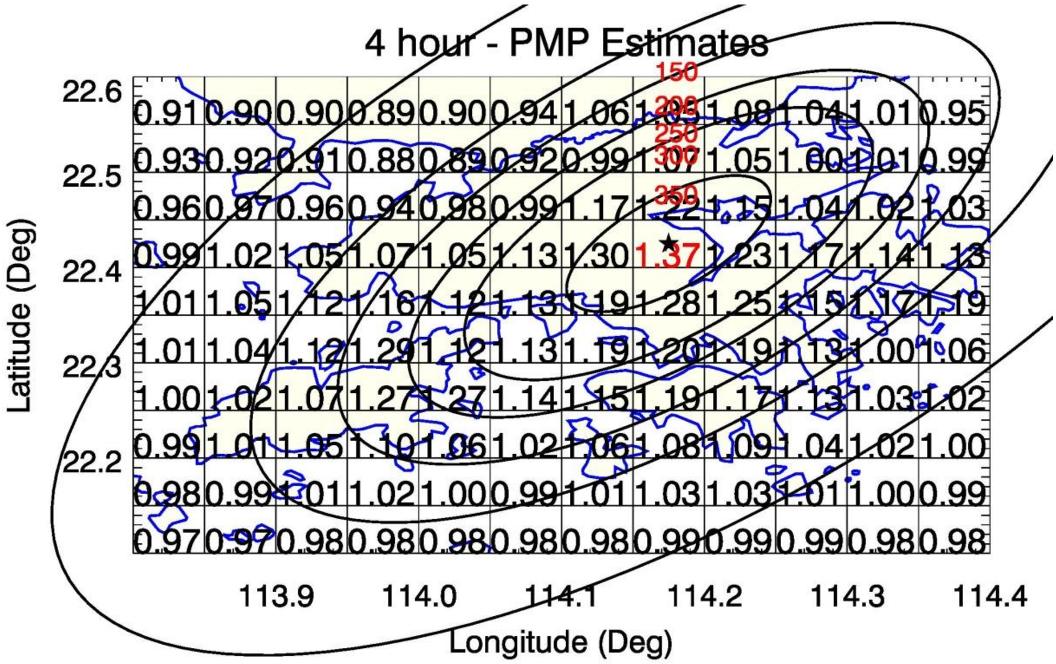


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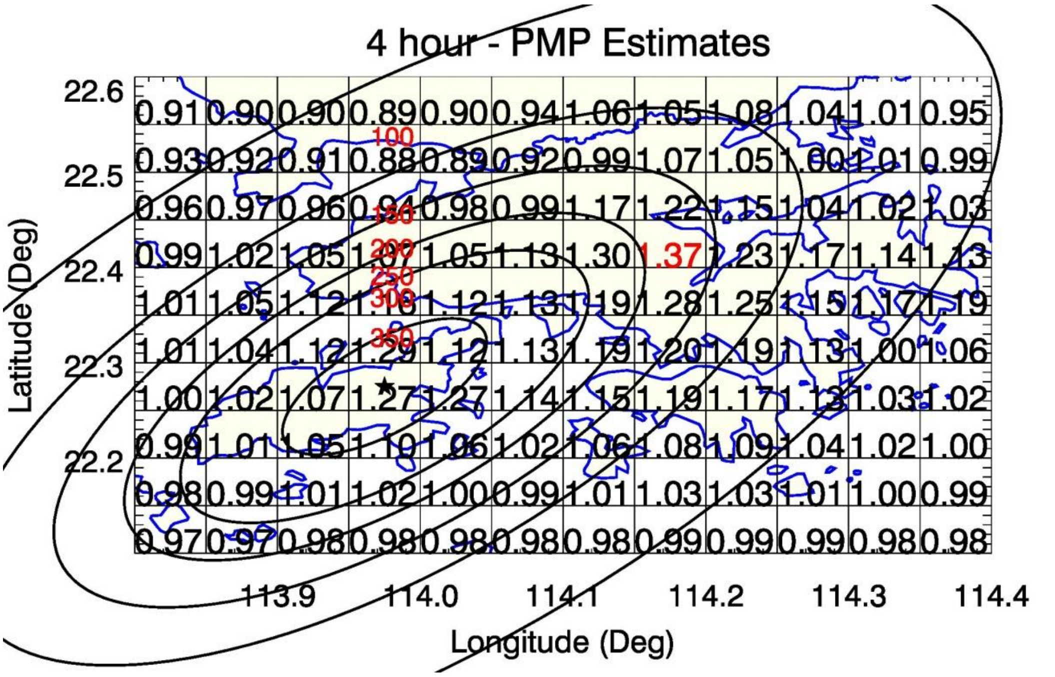


Centred at Lantau Island

**Figure C3 NE-SW Orientation 45° (Embryonic PMP)**

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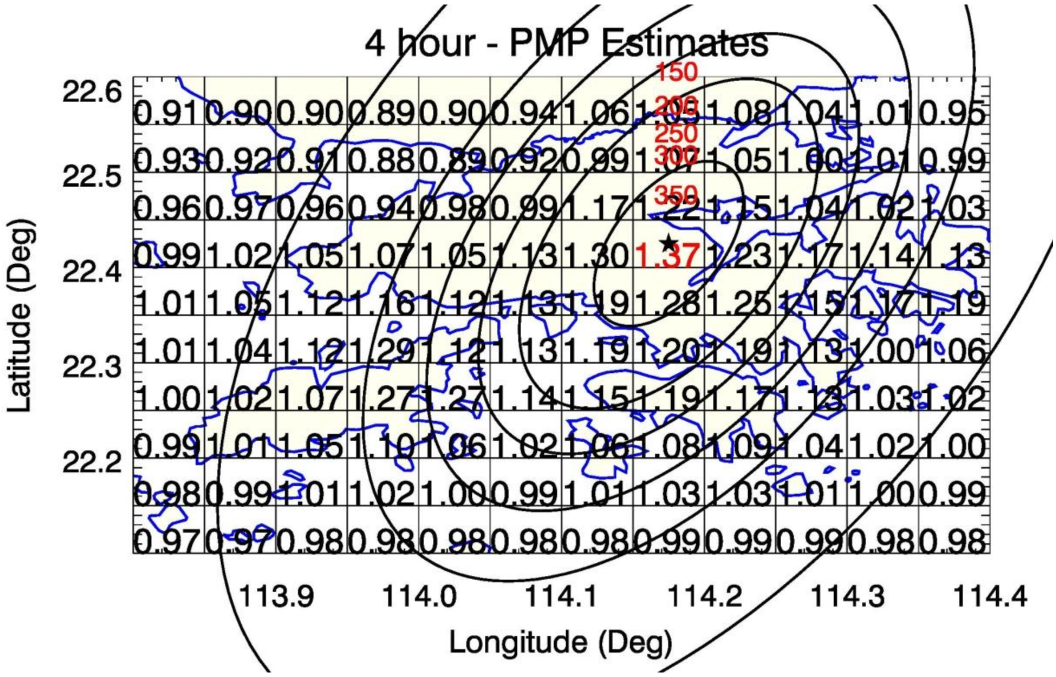
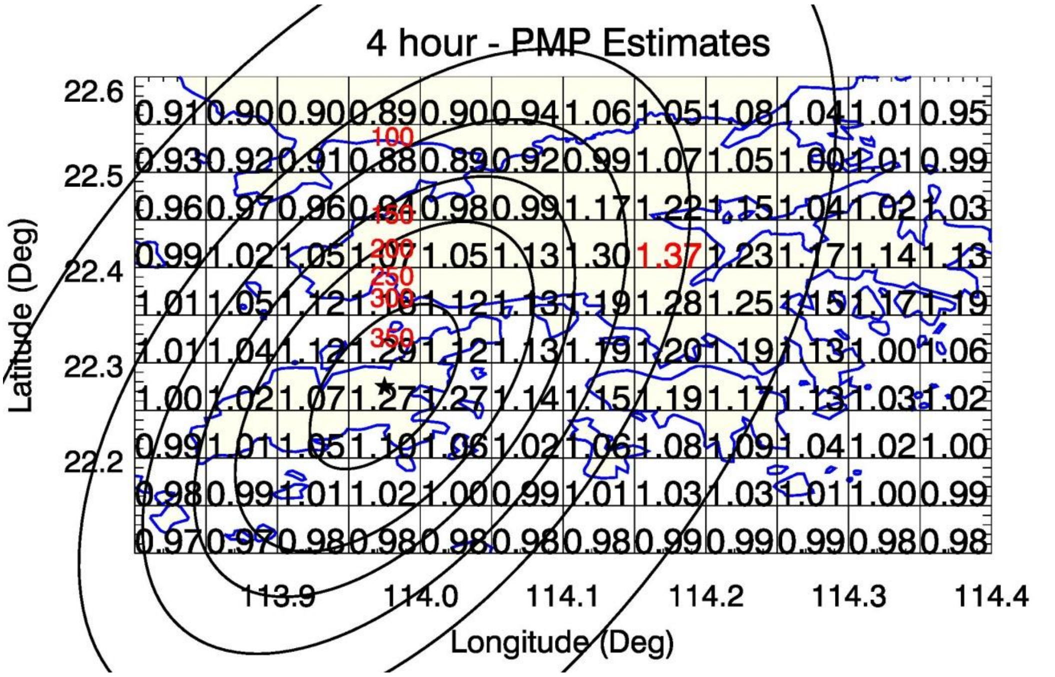



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C4 NNE-SSW Orientation 67.5° (Embryonic PMP)**

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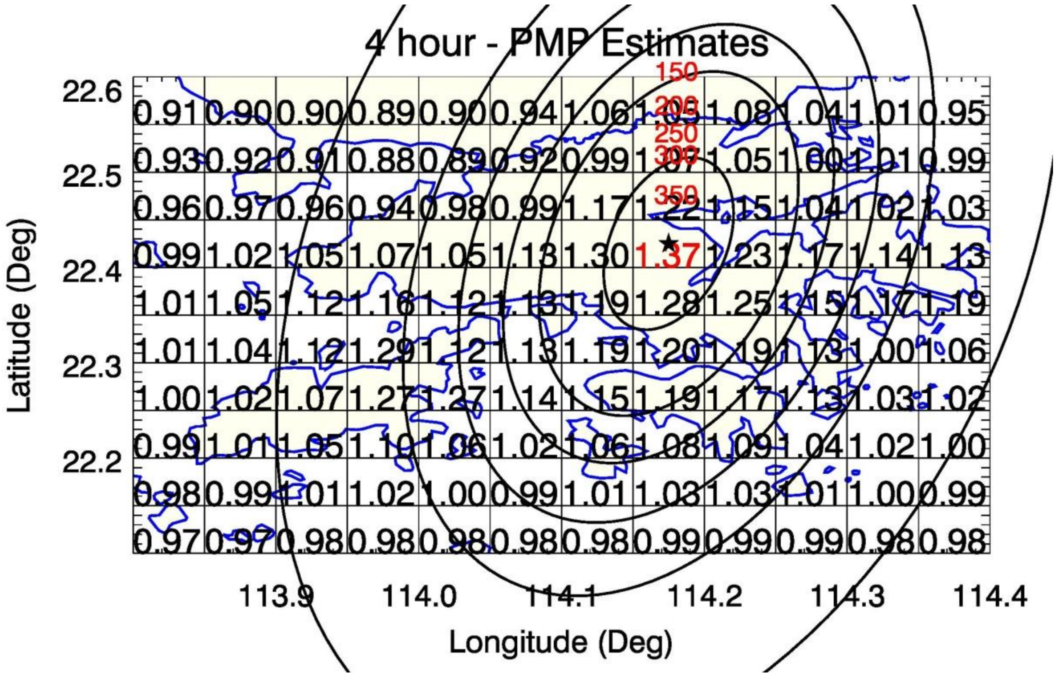


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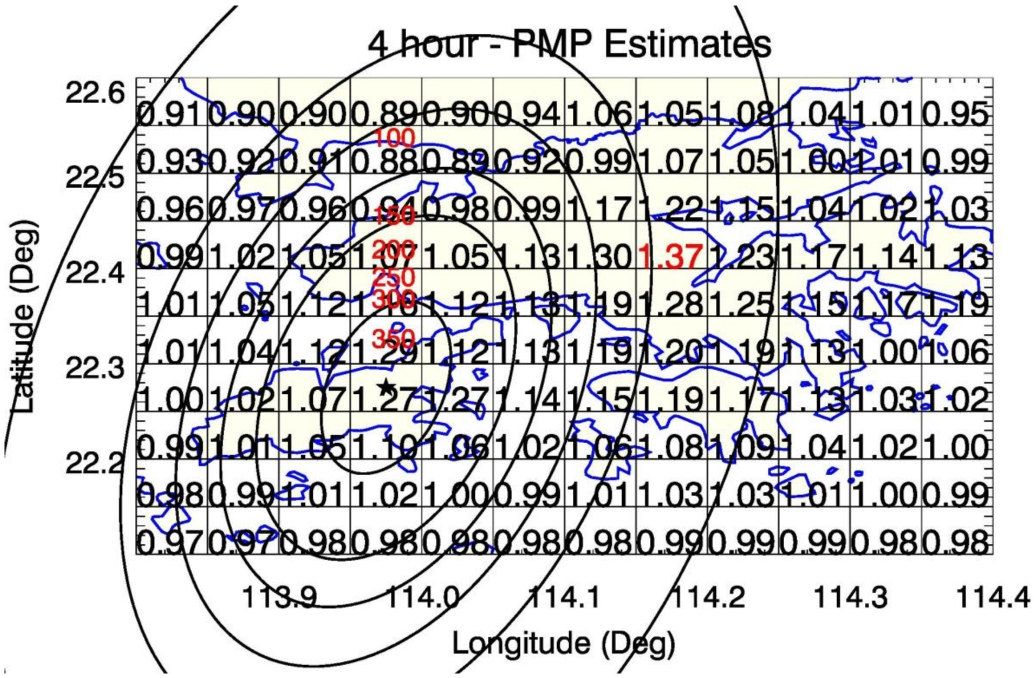


Centred at Lantau Island

**Figure C5   N-S Orientation 77.5° (Embryonic PMP)**

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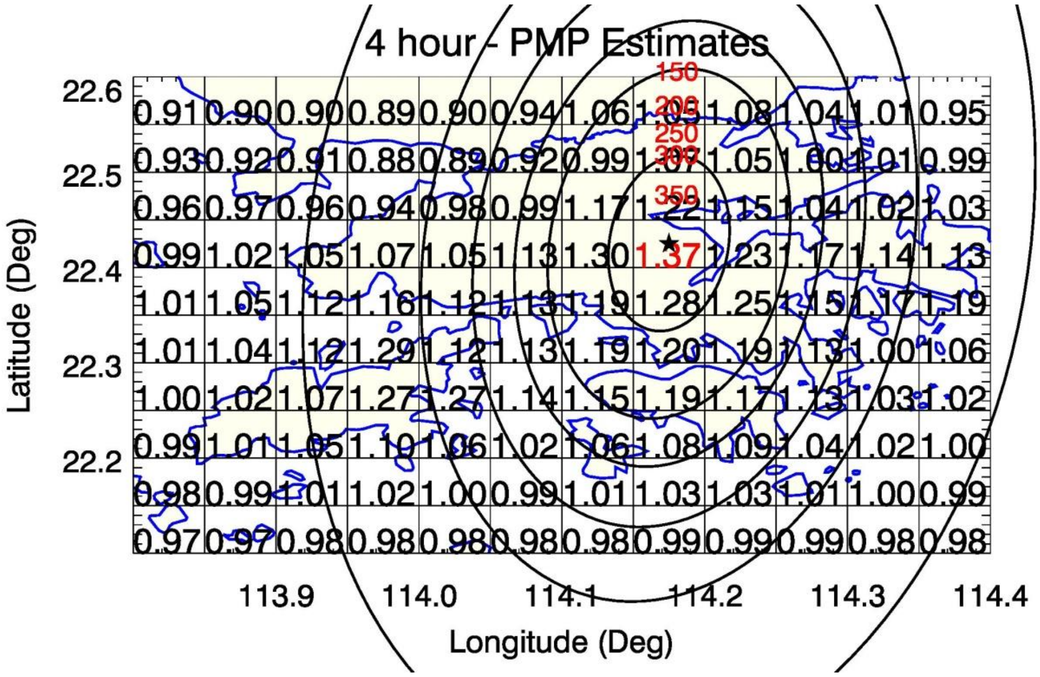


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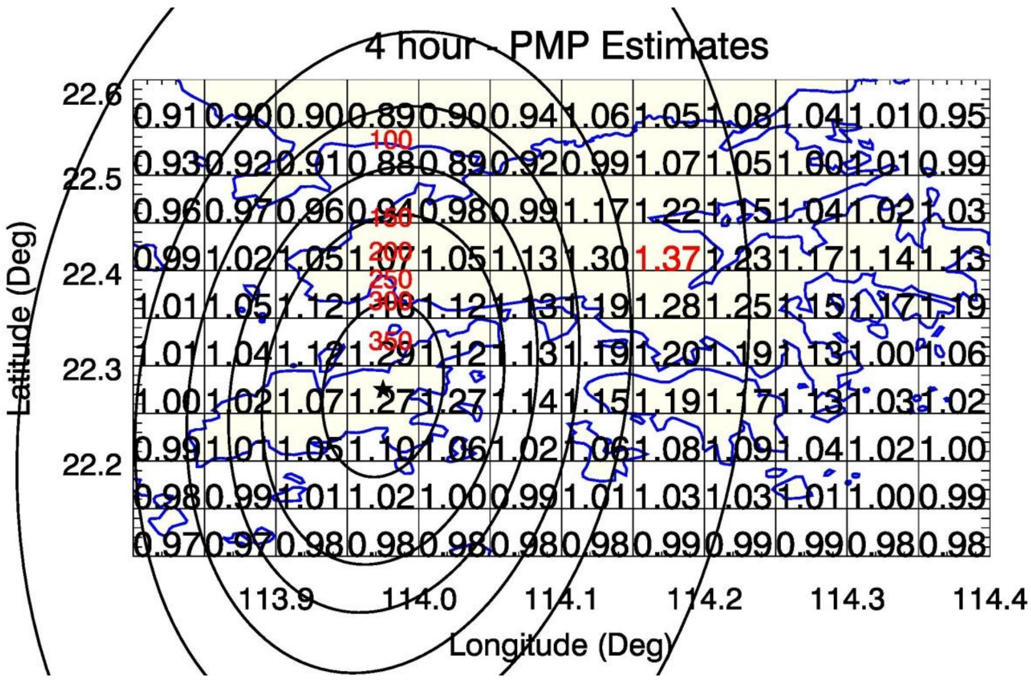


Centred at Lantau Island

**Figure C6 N-S Orientation 85° (Embryonic PMP)**

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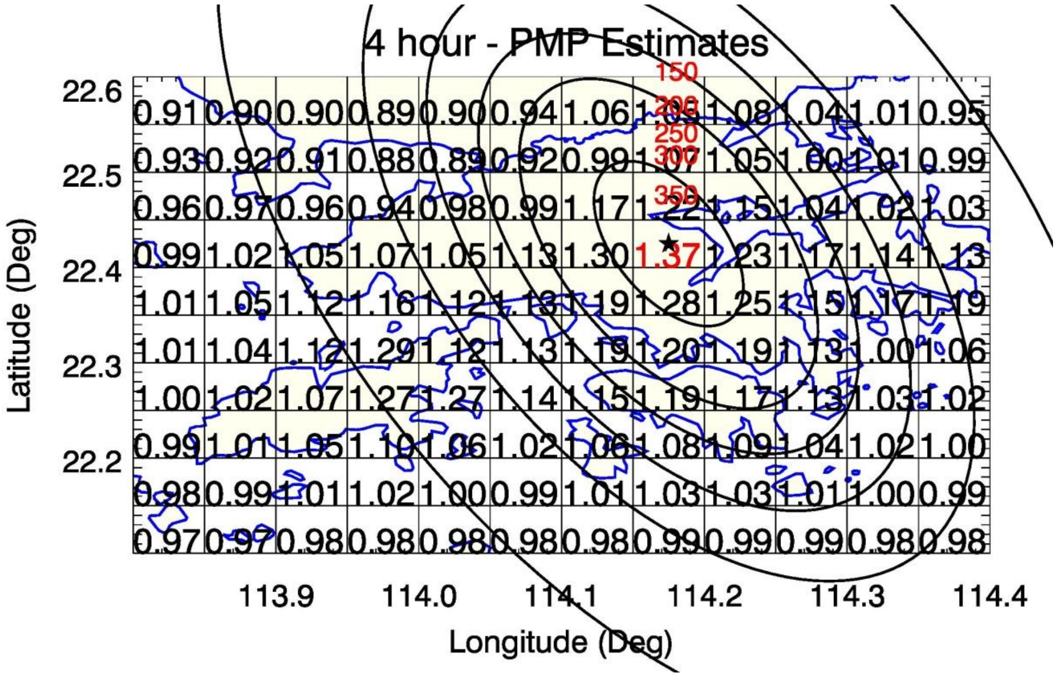
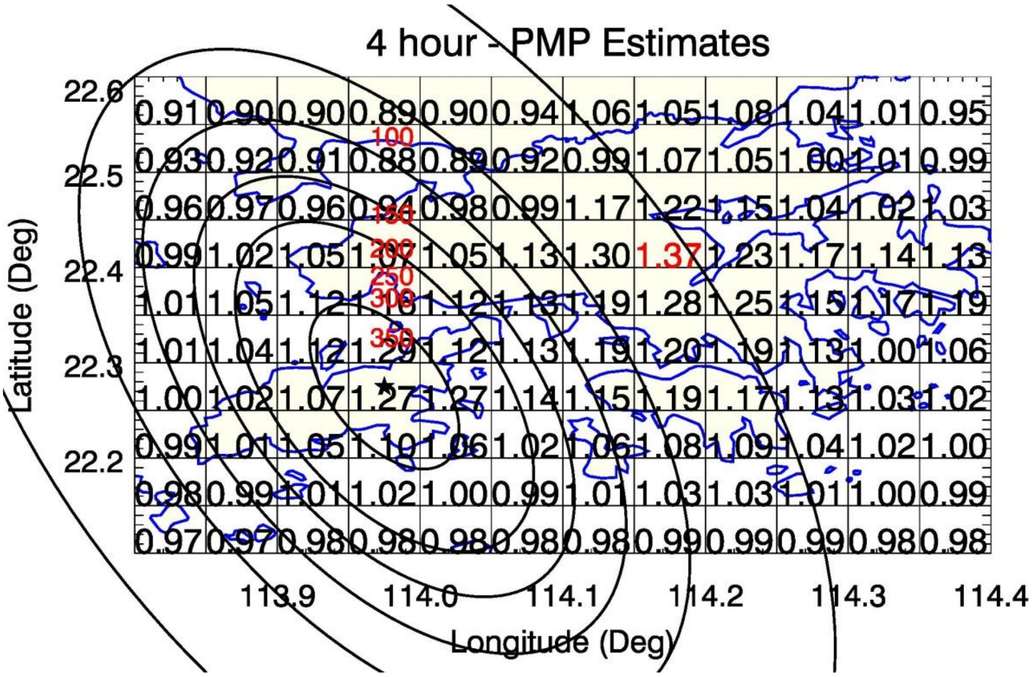



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C7 NNW-SSE Orientation 112.5° (Embryonic PMP)**

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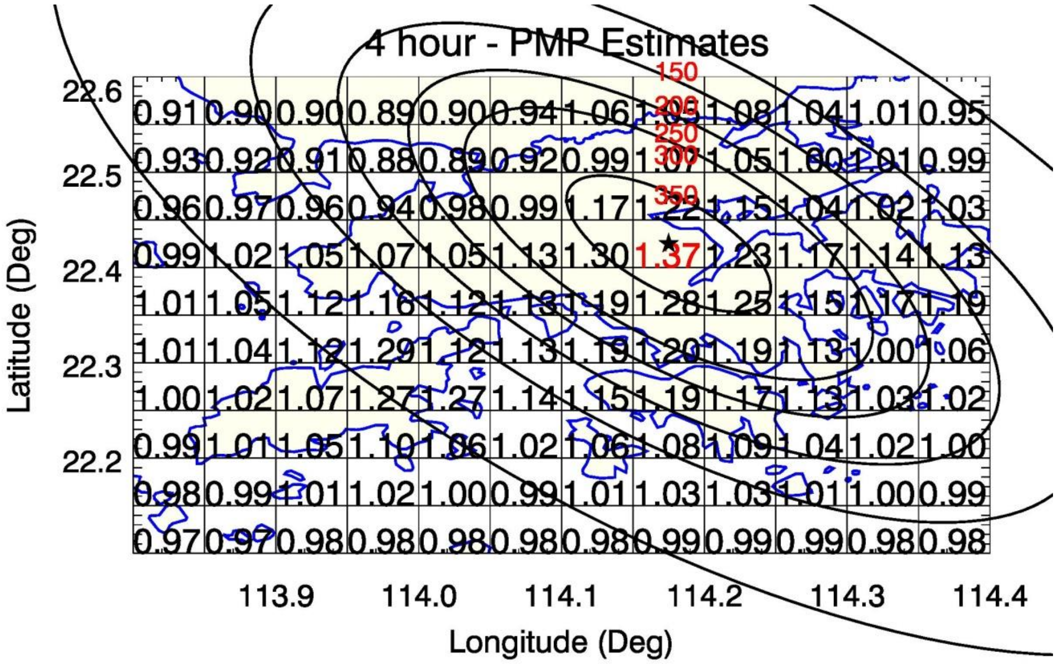
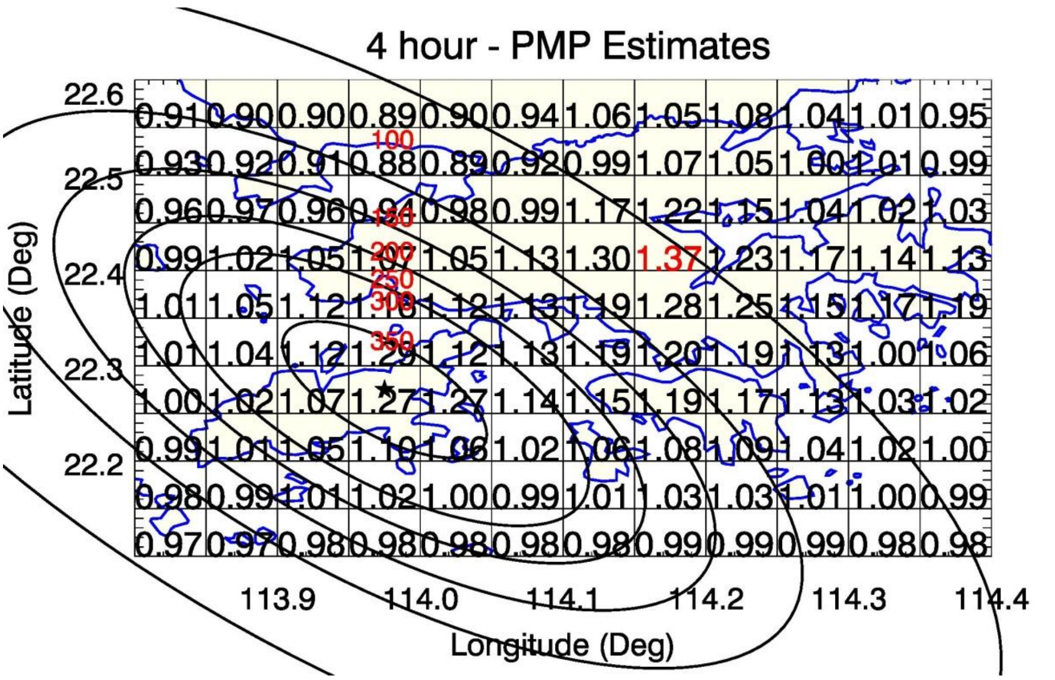



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C8 NW-SE Orientation 135° (Embryonic PMP)**

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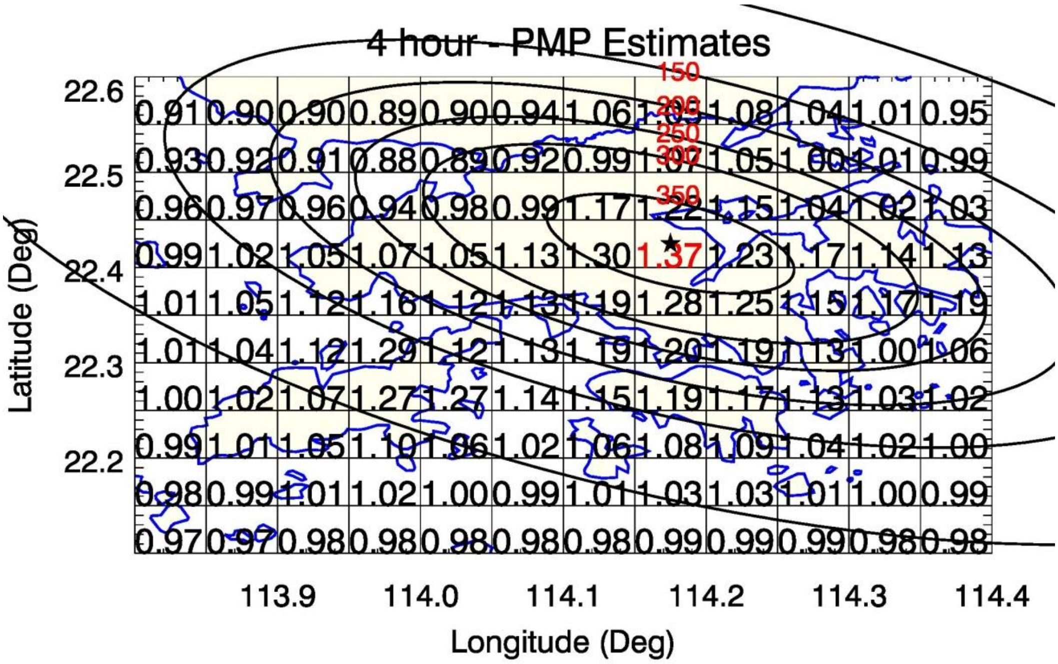
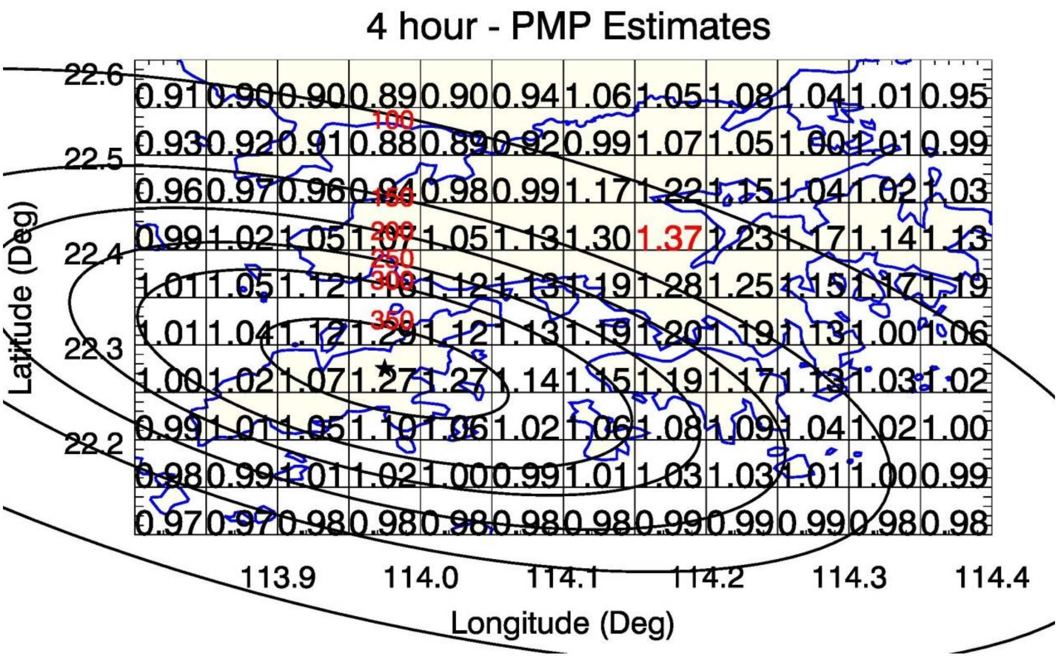



Centred at Tai Mo Shan




Centred at Lantau Island

**Figure C9 WNW-ESE Orientation 157.5° (Embryonic PMP)**

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# Appendix D

## Embryonic PMP in Grids and Isohyets with the Generalised Convergence Pattern Centred at Tai Mo Shan for a Complete Set of Orientation Adjustments

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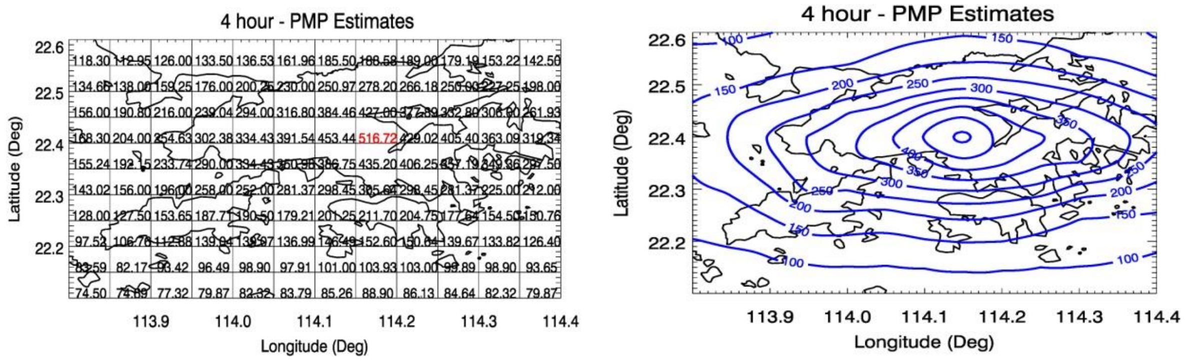
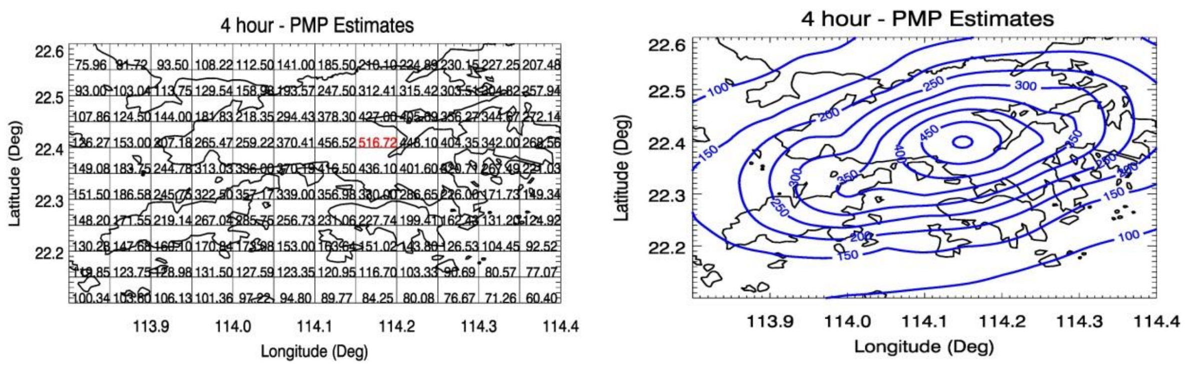
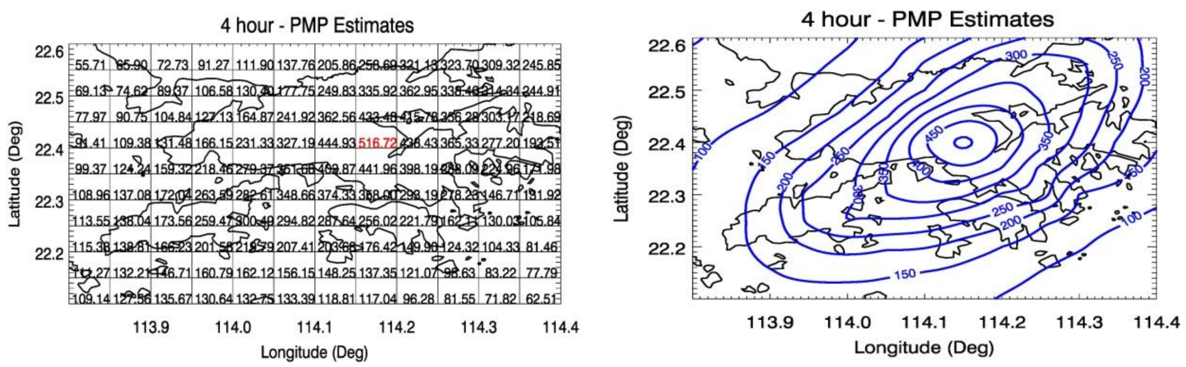



E-W Orientation 0°




ENE-WSW Orientation 22.5°




NE-SW Orientation 45°

**Figure D1 Embryonic PMP Centred at Tai Mo Shan (Sheet 1 of 3)**

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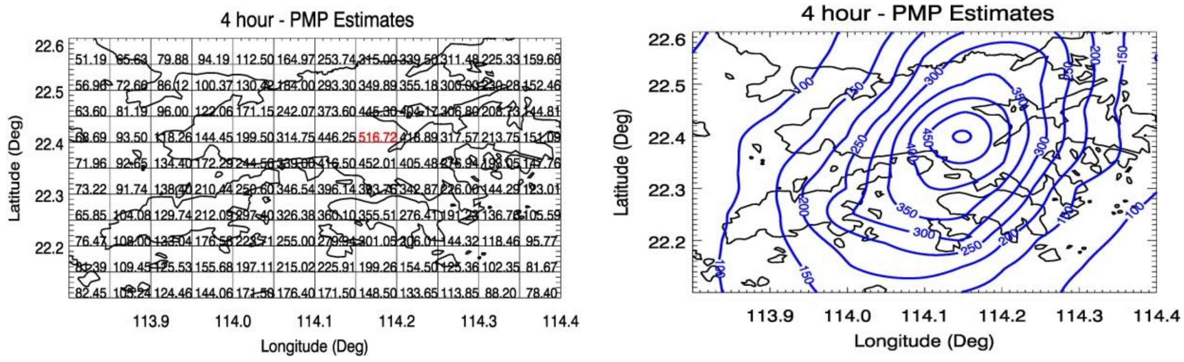
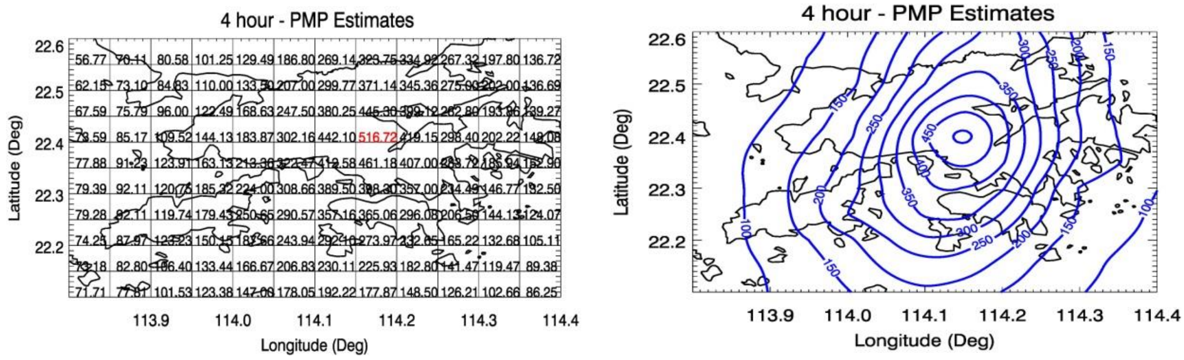
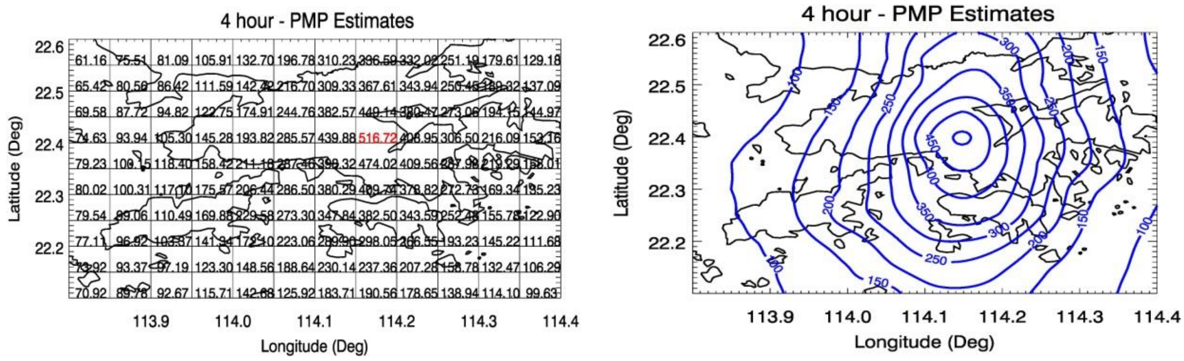



NNE-SSW Orientation 67.5°




N-S Orientation 77.5°




N-S Orientation 85°

**Figure D1 Embryonic PMP Centred at Tai Mo Shan (Sheet 2 of 3)**

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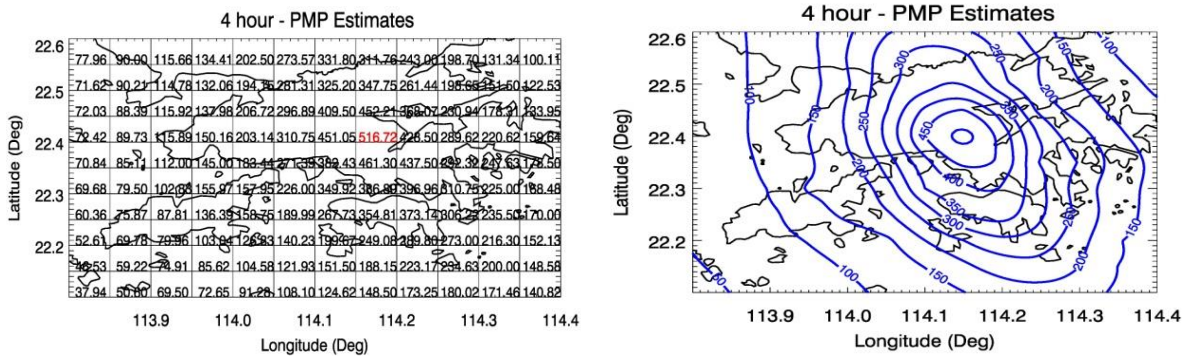
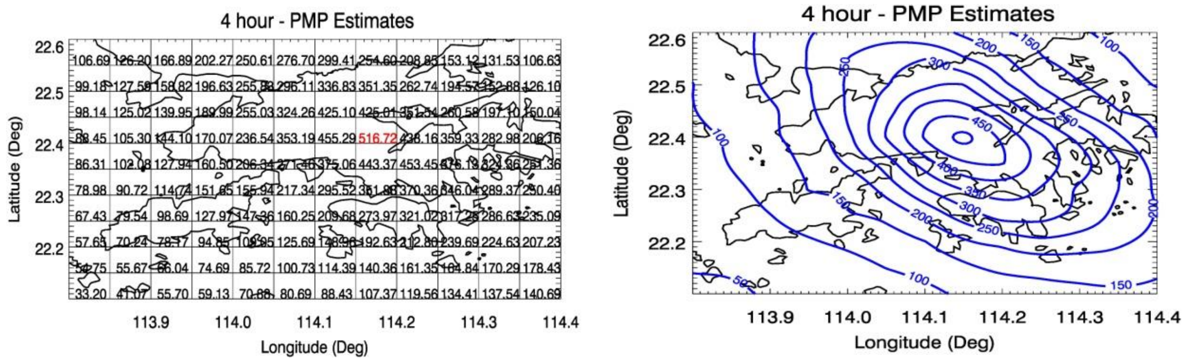
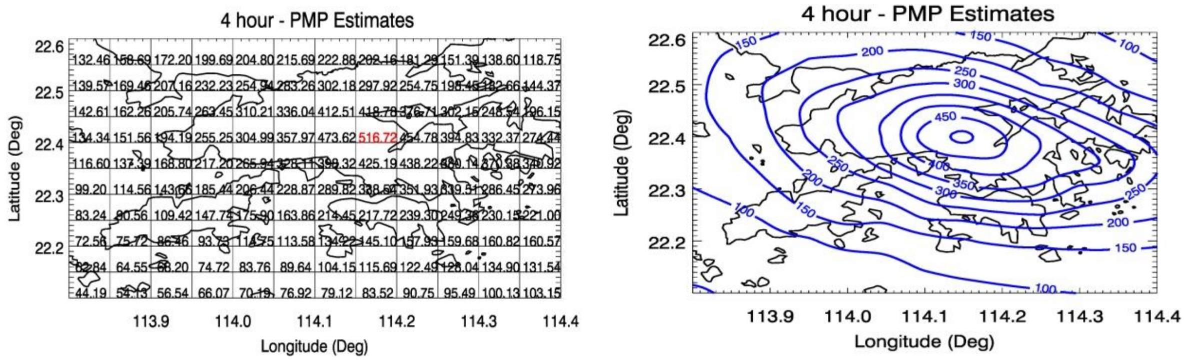



NNW-SSE Orientation 112.5°




NW-SE Orientation 135°




WNW-ESE Orientation 157.5°

**Figure D1 Embryonic PMP Centred at Tai Mo Shan (Sheet 3 of 3)**

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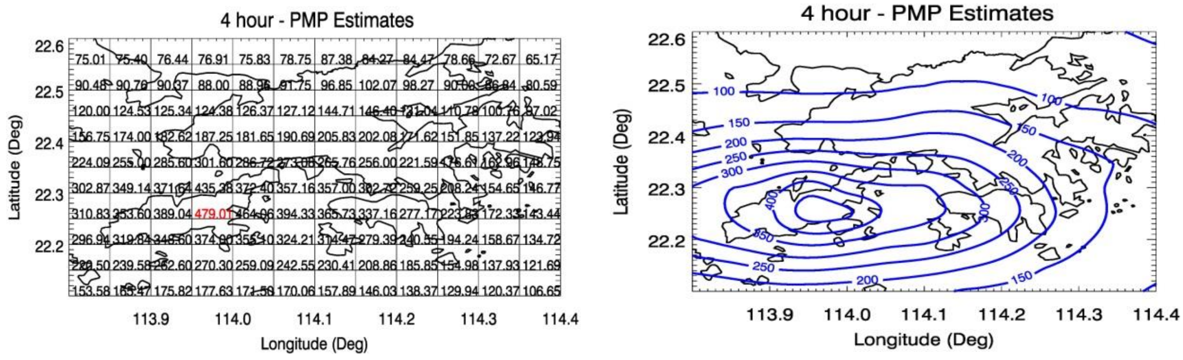
# Appendix E

## Embryonic PMP in Grids and Isohyets with the Generalised Convergence Pattern Centred at Lantau Island for a Complete Set of Orientation Adjustments

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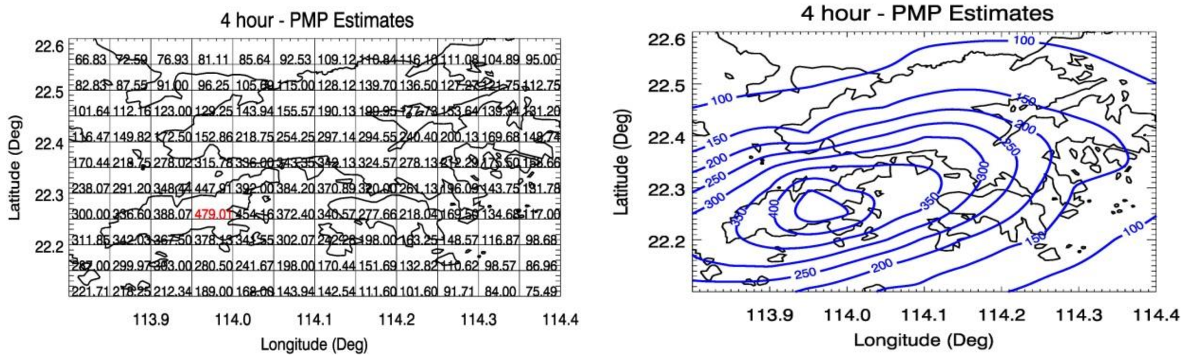
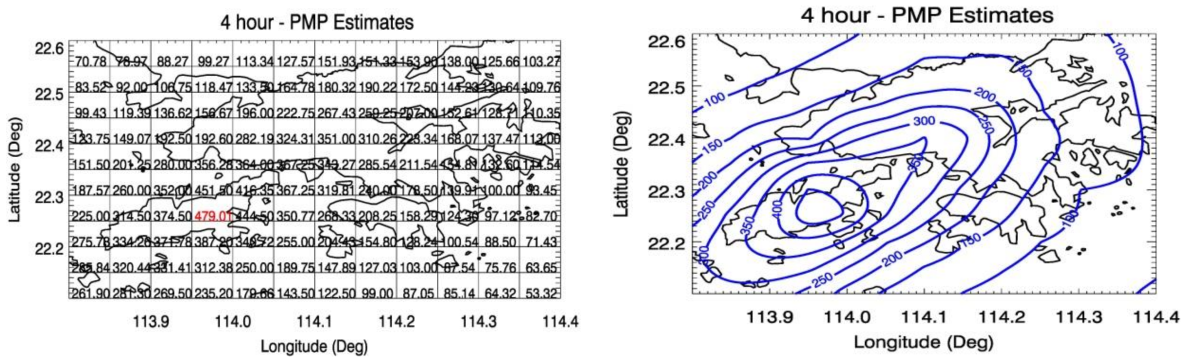



ENE-WSW Orientation 22.5°




NE-SW Orientation 45°

**Figure E1 Embryonic PMP Centred at Lantau Island (Sheet 1 of 3)**

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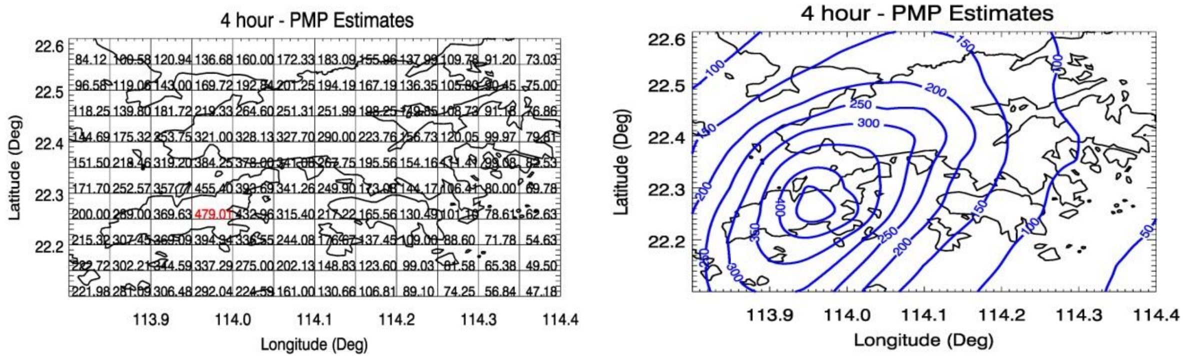
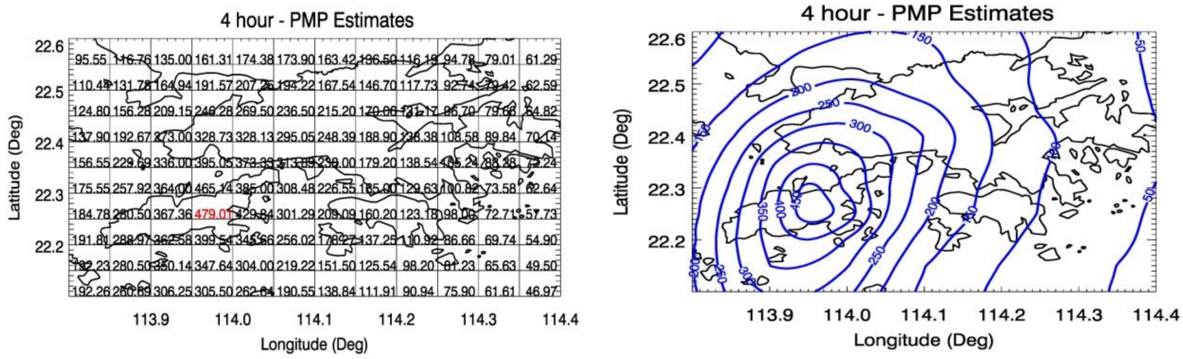
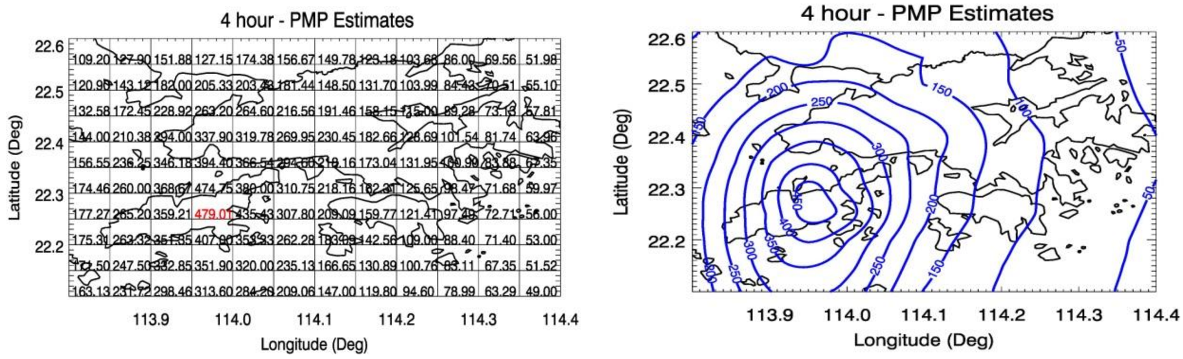



NNE-SSW Orientation 67.5°




N-S Orientation 77.5°




N-S Orientation 85°

**Figure E1 Embryonic PMP Centred at Lantau Island (Sheet 2 of 3)**

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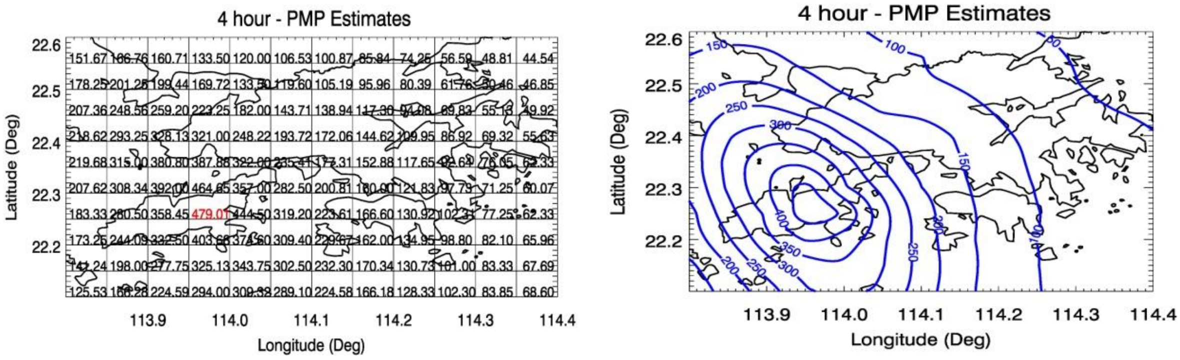
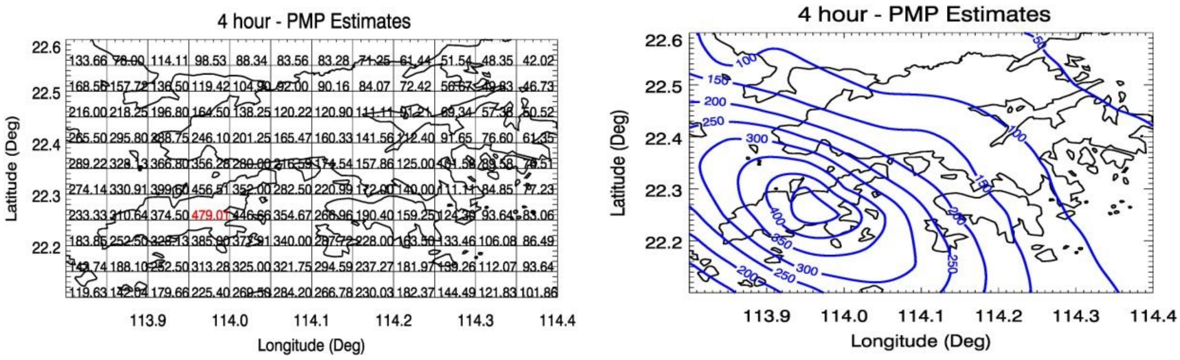
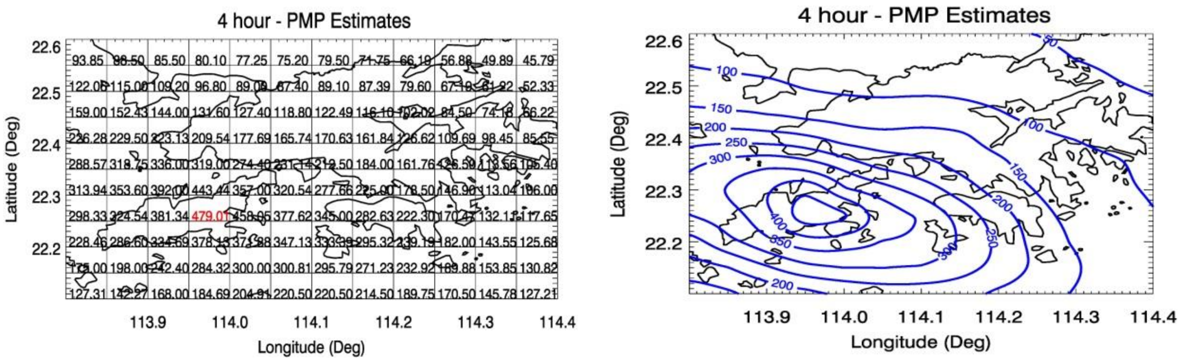



NNW-SSE Orientation 112.5°




NW-SE Orientation 135°




WNW-ESE Orientation 157.5°

**Figure E1 Embryonic PMP Centred at Lantau Island (Sheet 3 of 3)**

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# Appendix F

## 4-hour Isohyets from Storm Transposition with Moisture Maximisation for a Complete Set of Orientation Adjustments

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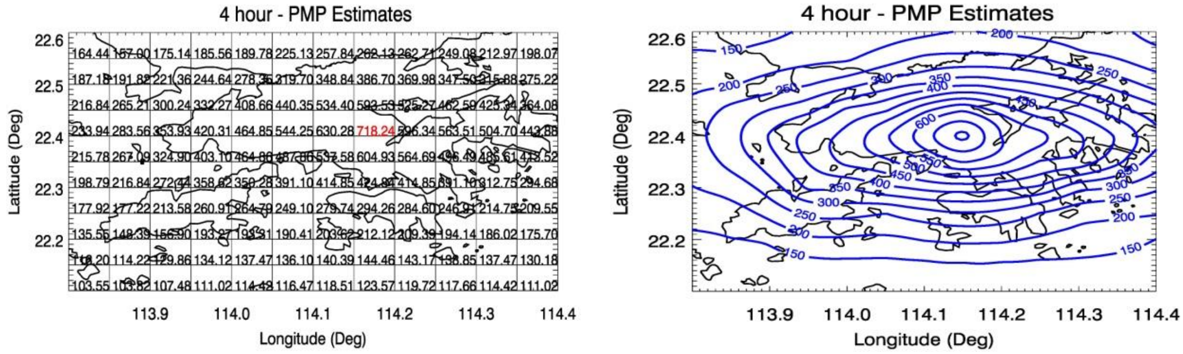


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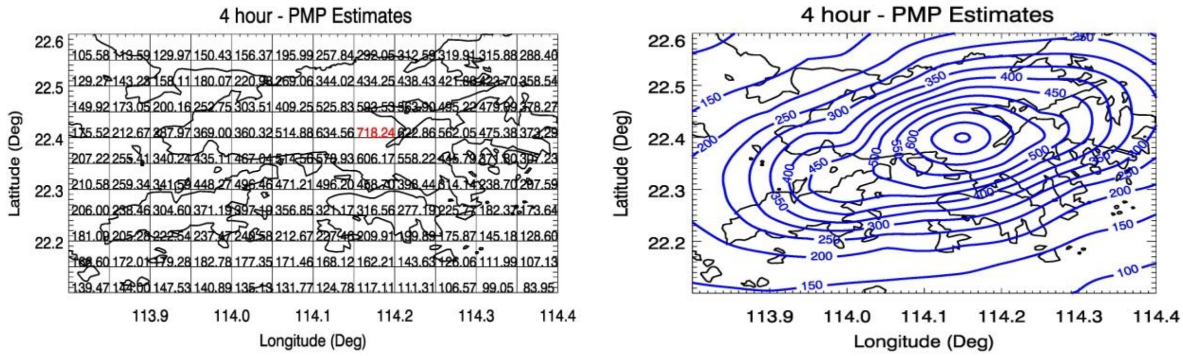
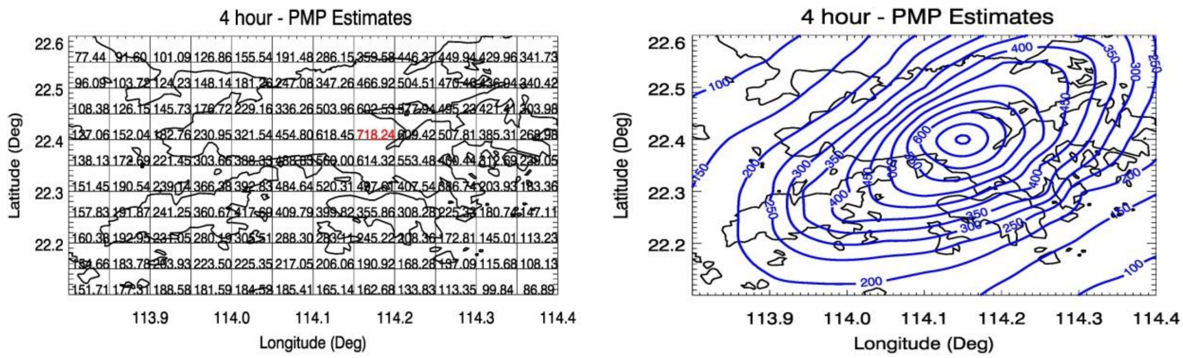



ENE-WSW Orientation 22.5°




NE-SW Orientation 45°

**Figure F1 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Tai Mo Shan (Sheet 1 of 3)**

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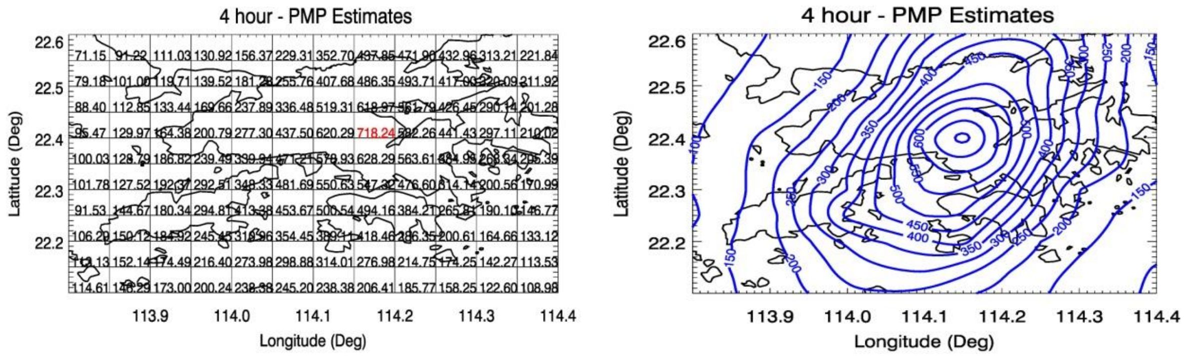
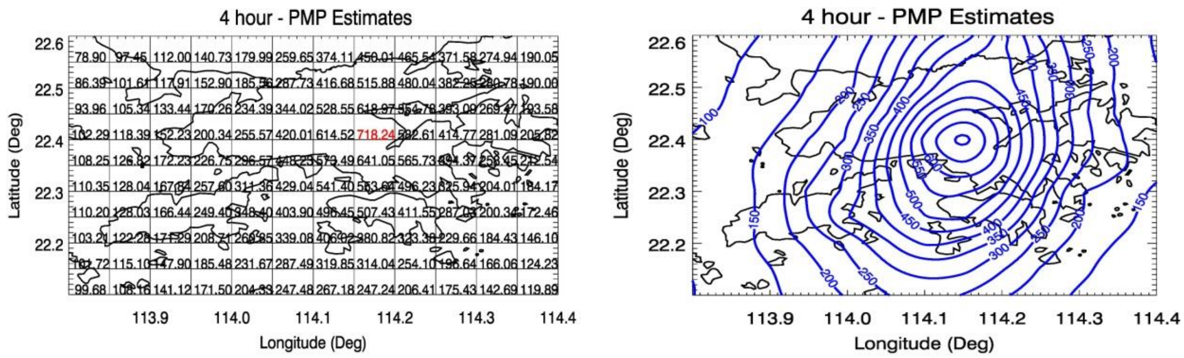
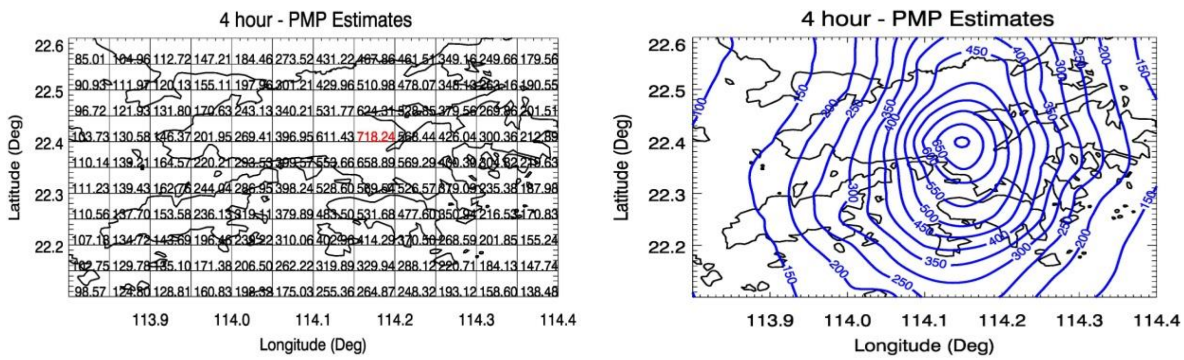



NNE-SSW Orientation 67.5°




N-S Orientation 77.5°




N-S Orientation 85°

**Figure F1 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Tai Mo Shan (Sheet 2 of 3)**

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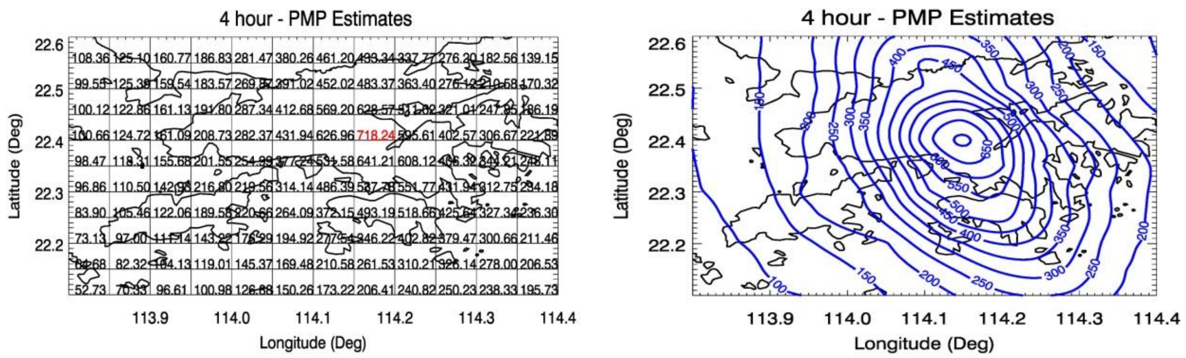
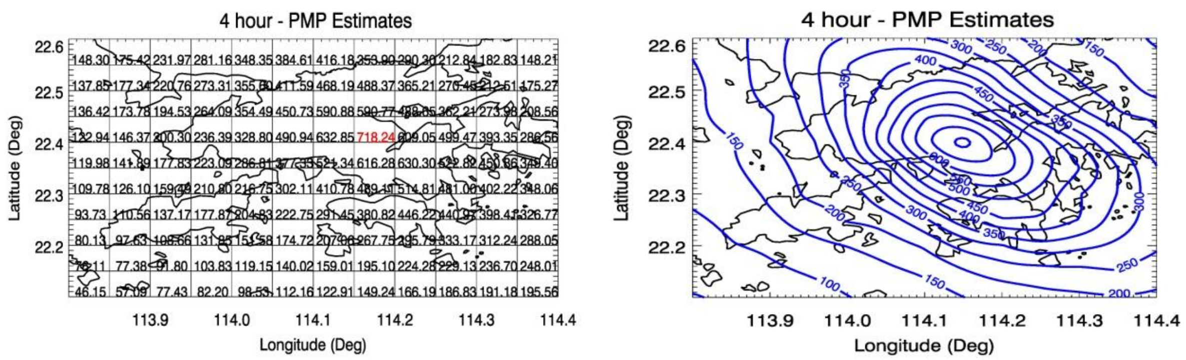
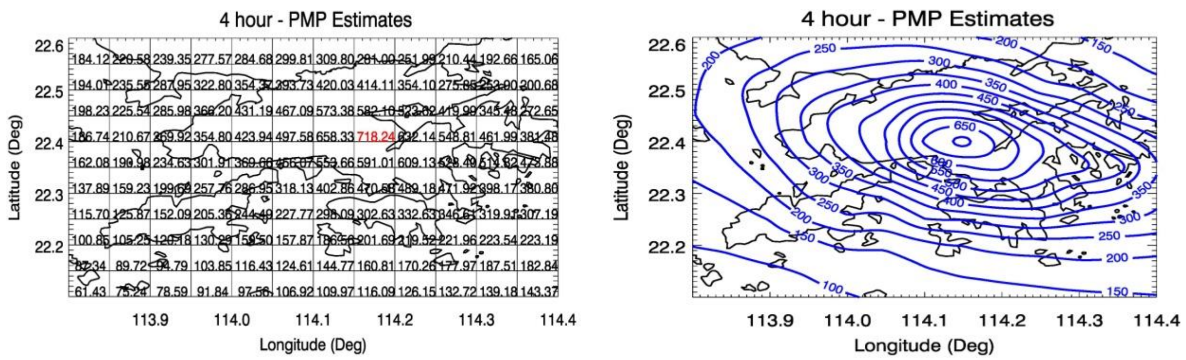



NNW-SSE Orientation 112.5°




NW-SE Orientation 135°




WNW-ESE Orientation 157.5°

**Figure F1 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Tai Mo Shan (Sheet 3 of 3)**

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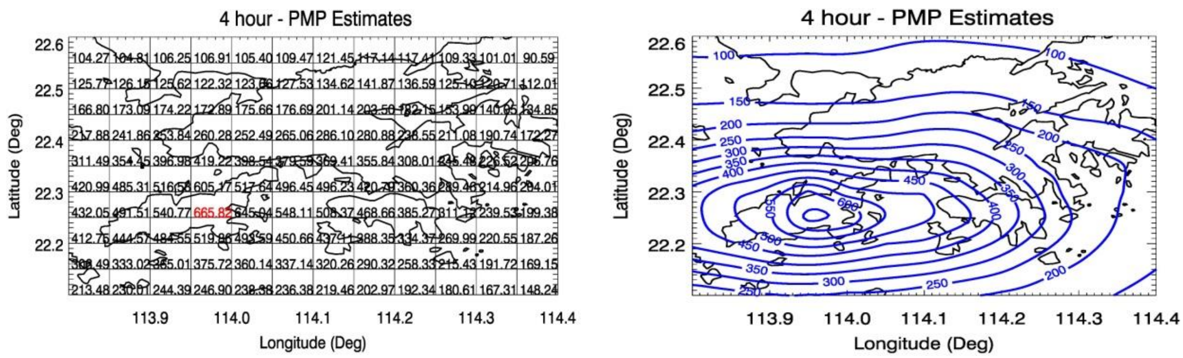
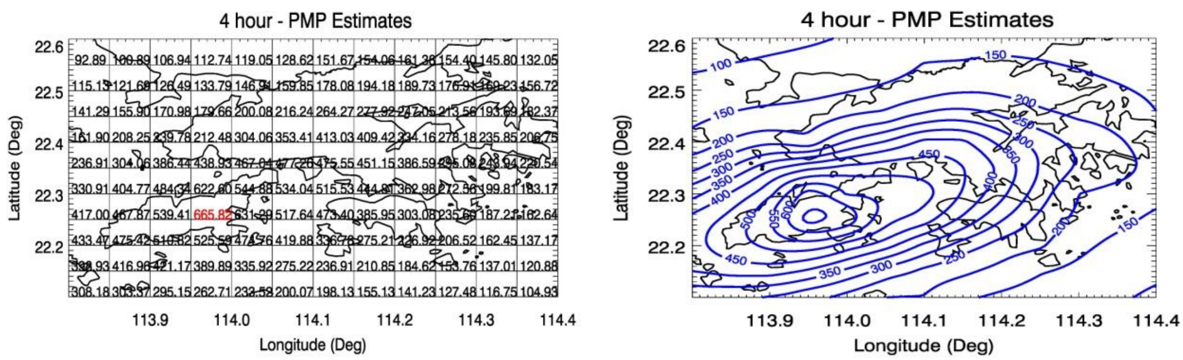
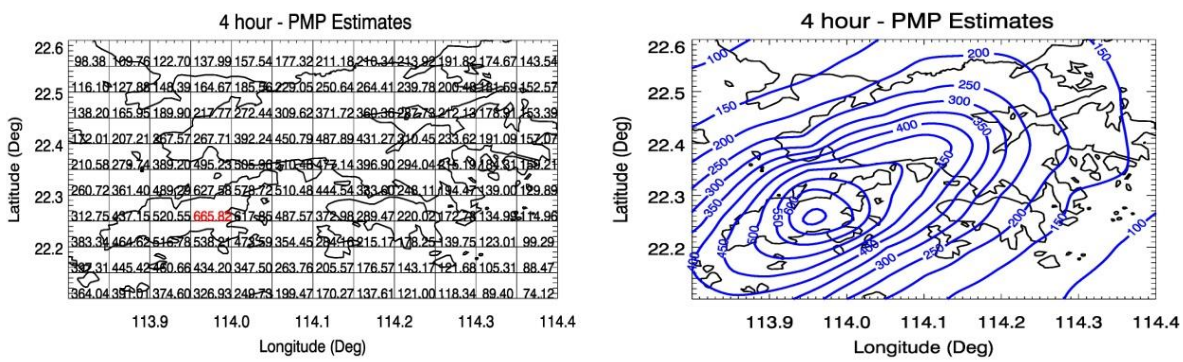



E-W Orientation 0°




ENE-WSW Orientation 22.5°




NE-SW Orientation 45°

**Figure F2 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Lantau Island (Sheet 1 of 3)**

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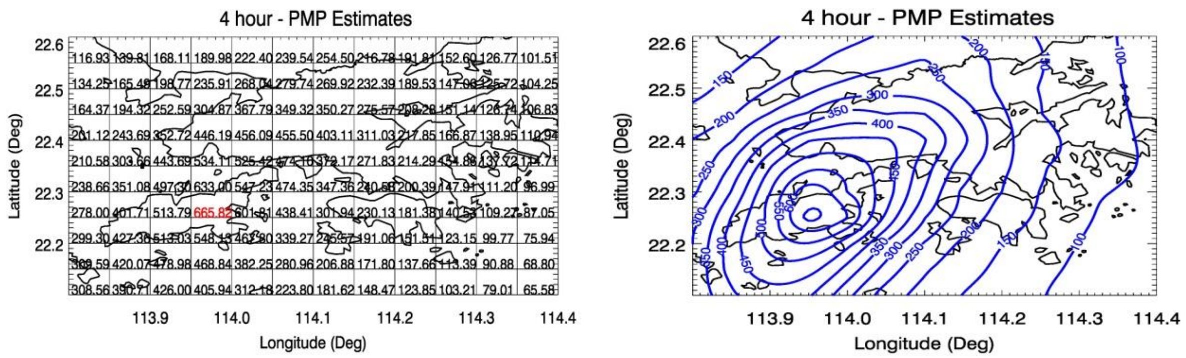
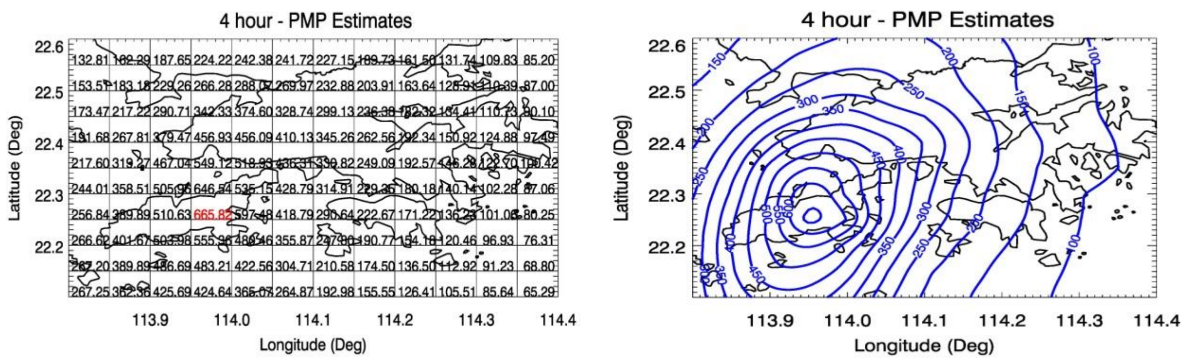
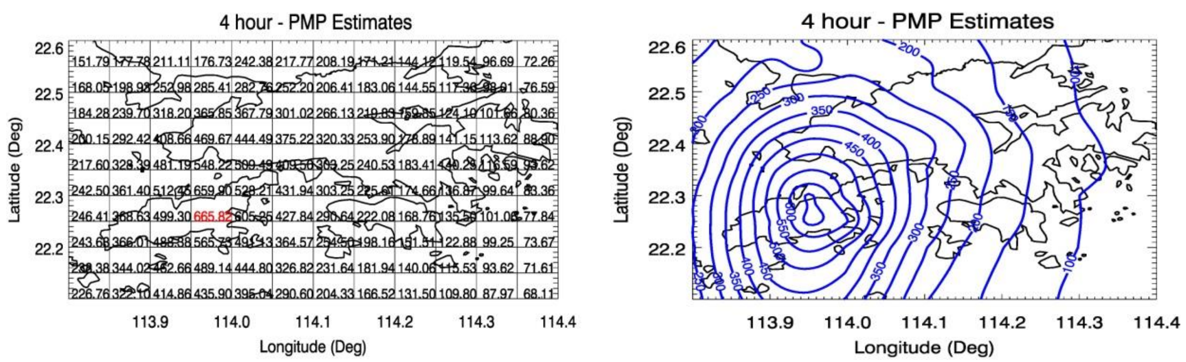



NNE-SSW Orientation 67.5°




N-S Orientation 77.5°




N-S Orientation 85°

**Figure F2 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Lantau Island (Sheet 2 of 3)**

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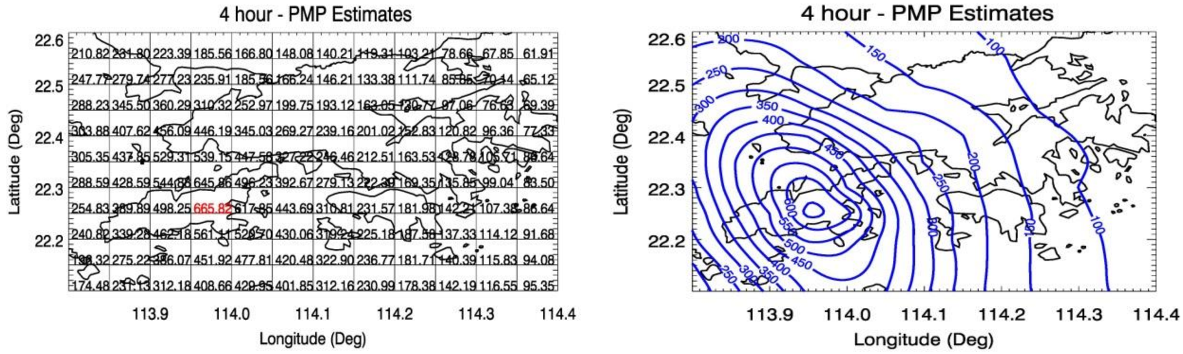
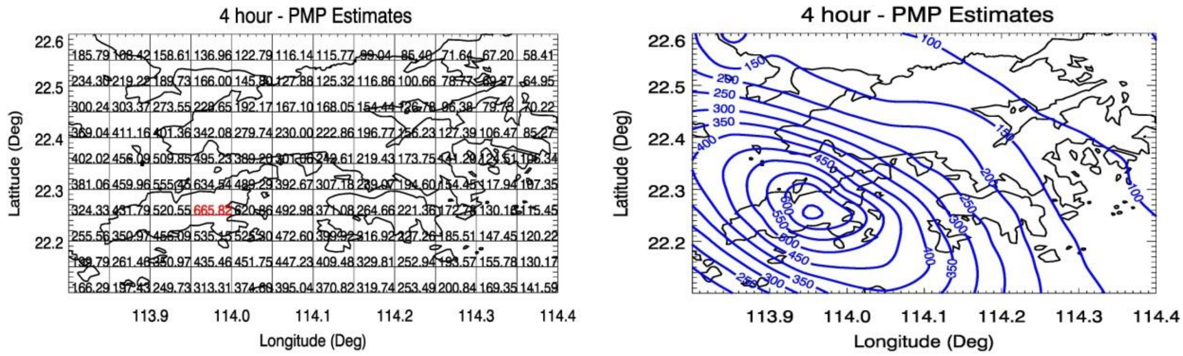
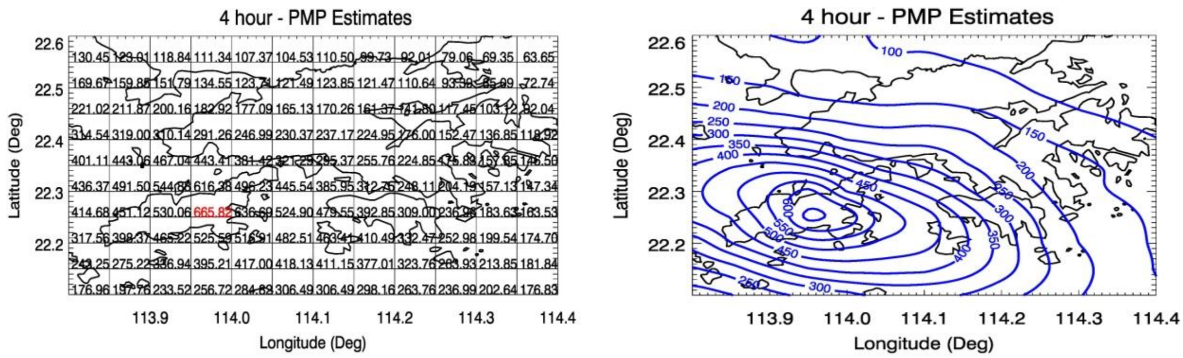



NNW-SSE Orientation 112.5°




NW-SE Orientation 135°




WNW-ESE Orientation 157.5°

**Figure F2 Moisture-maximized 4-hour Isohyets for Storm Transposition Centred at Lantau Island (Sheet 3 of 3)**

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# Appendix G

# Results of DAD Analyses

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Based on the lists of top storms for 4-hour rainfalls as shown in Table H1, the following DAD curves were produced.

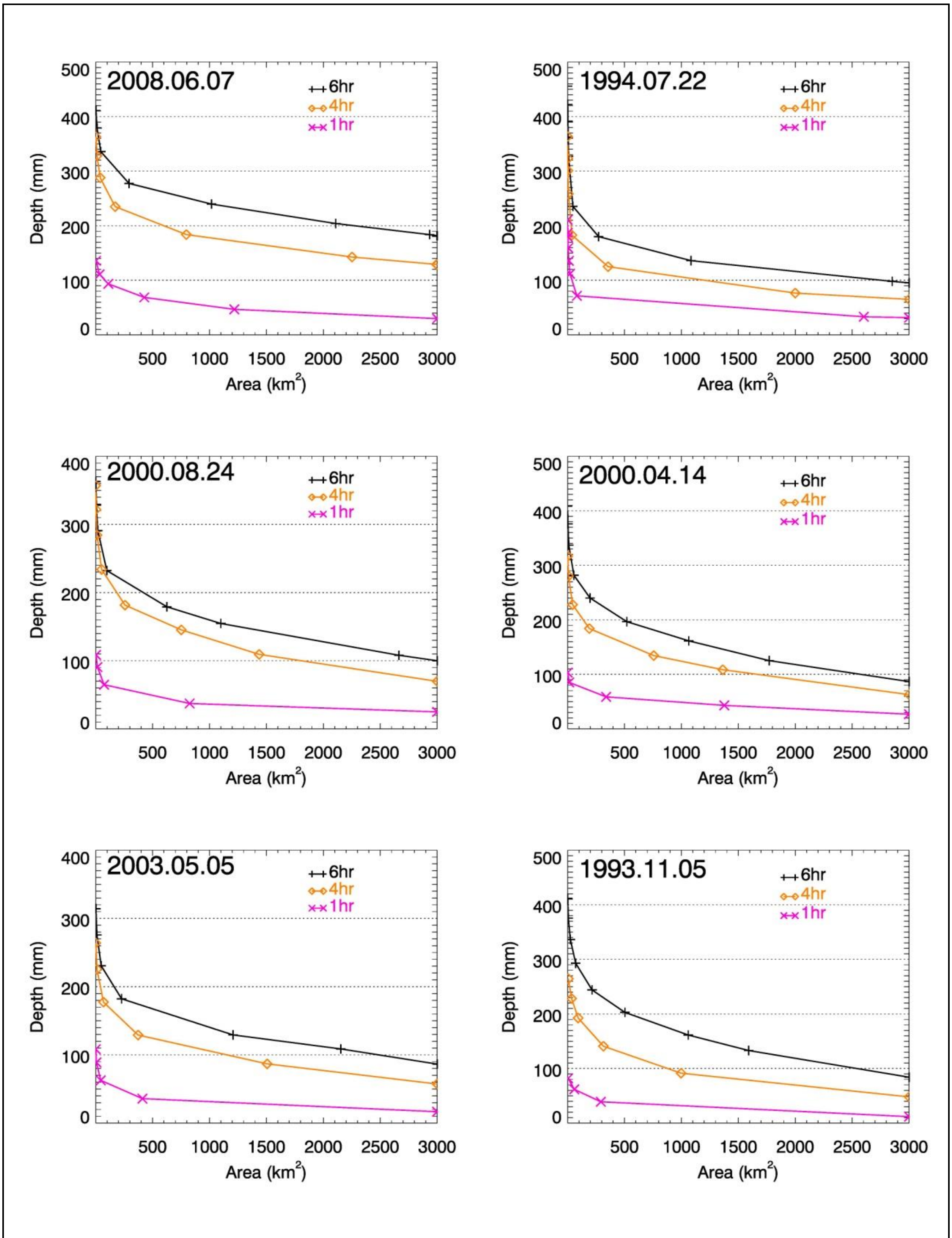


**Figure G1 DAD Curves for Top 15 Storms between 1984 and 2015 (Sheet 1 of 3)**

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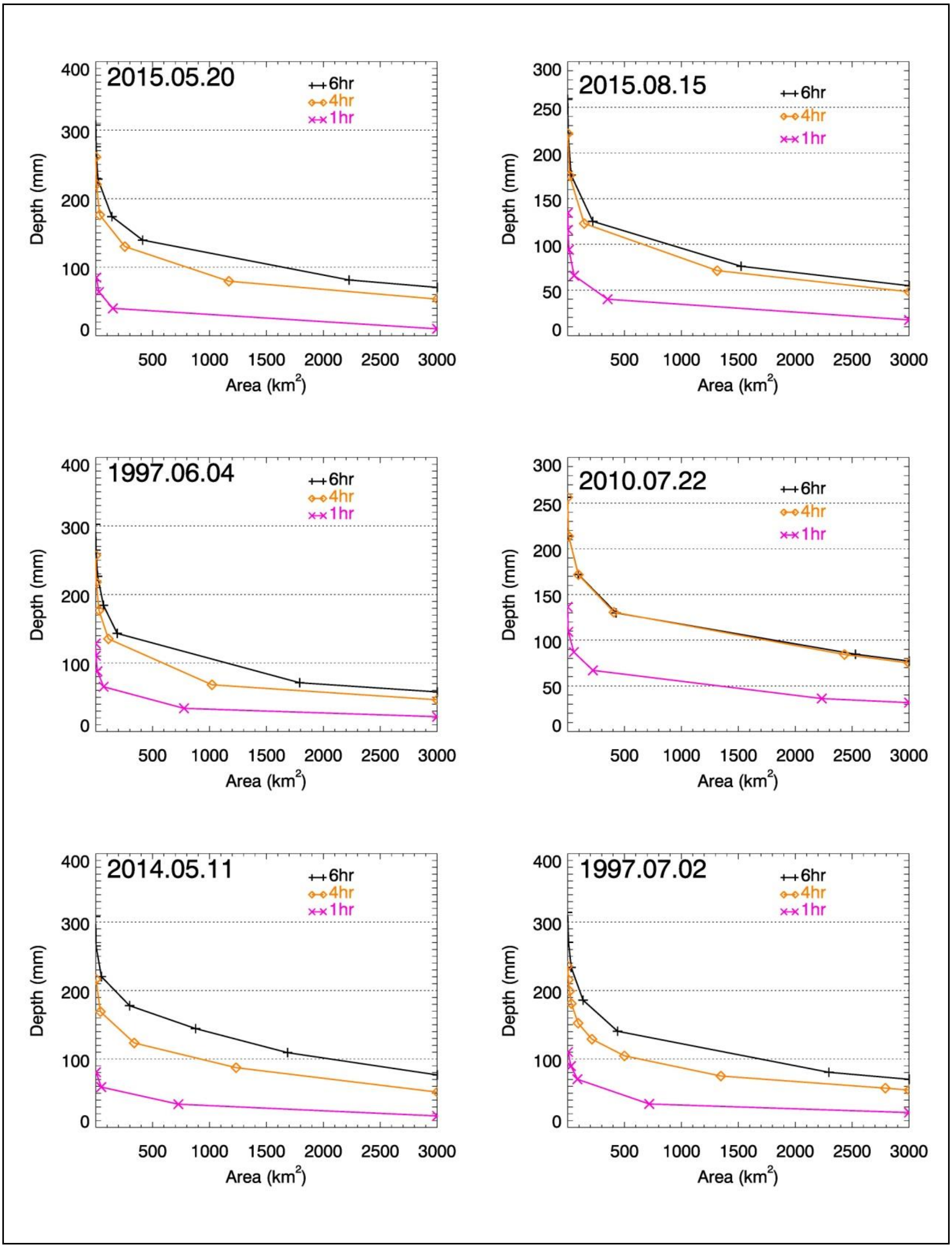


**Figure G1 DAD Curves for Top 15 Storms between 1984 and 2015 (Sheet 2 of 3)**

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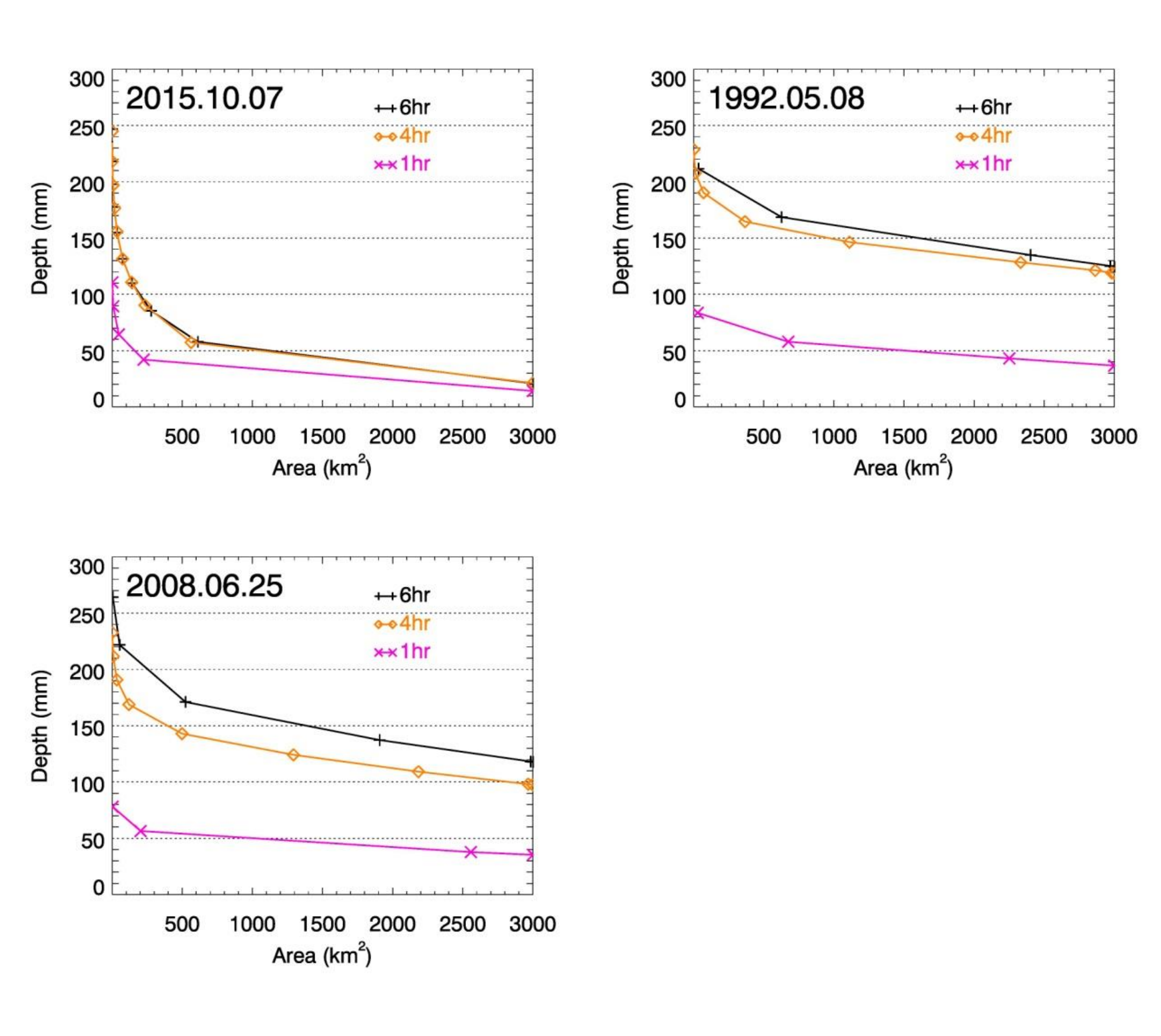


**Figure G1 DAD Curves for Top 15 Storms between 1984 and 2015 (Sheet 3 of 3)**

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# Appendix H

## Depth-Area Relation for 4-hour for Top 15 Storms in Hong Kong

**Table H1 Depth-Area Relation for 4-hour for Top 15 Storms in Hong Kong (Sheet 1 of 3)**

| 7-Jun-2008 | | 22-Jul-1994 | | 24-Aug-2000 | | 14-Apr-2000 | | 5-May-2003 | |
|---|---|---|---|---|---|---|---|---|---|
| Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) |
| 0.6 | 378.84 | 0.3 | 357 | 0.9 | 355.14 | 3.3 | 330.51 | 9.6 | 284.68 |
| 11.1 | 360.15 | 1.2 | 341.24 | 12.6 | 336.79 | 28.8 | 312.78 | 33.9 | 268.64 |
| 52.5 | 340.26 | 4.2 | 320.9 | 34.8 | 320.18 | 92.4 | 294.06 | 53.4 | 256.92 |
| 118.8 | 324.95 | 8.7 | 303.02 | 85.2 | 299.75 | 230.4 | 274.63 | 81.9 | 240.94 |
| 194.1 | 310.52 | 15.3 | 285.13 | 197.7 | 277.91 | 354 | 262.12 | 131.4 | 220.15 |
| 262.5 | 297.91 | 25.2 | 265.86 | 270.6 | 267.36 | 444.9 | 251.96 | 231.6 | 195.17 |
| 339 | 284.21 | 37.5 | 248.33 | 329.4 | 257.58 | 547.5 | 239.78 | 354.9 | 175.02 |
| 433.5 | 268.5 | 67.5 | 220.1 | 408 | 243.69 | 734.4 | 219.91 | 548.7 | 152.51 |
| 613.8 | 244.45 | 179.1 | 183.56 | 528 | 225.51 | 888.9 | 205.68 | 793.8 | 132.56 |
| 832.2 | 222.8 | 333.3 | 161.74 | 615 | 213.1 | 1044.3 | 191.82 | 1031.7 | 116.14 |
| 1050.6 | 205.1 | 525.6 | 143.82 | 725.7 | 197.76 | 1202.7 | 178.12 | 1407.6 | 94.77 |
| 1335.3 | 185.1 | 746.1 | 126.97 | 853.2 | 181.18 | 1386.9 | 162.69 | 2594.7 | 55.9 |
| 1765.5 | 161.23 | 1127.1 | 104.27 | 1021.8 | 161.61 | 1635.3 | 143.59 | 3000 | 47.93 |
| 2435.1 | 134.01 | 2095.2 | 73.73 | 1267.5 | 137.21 | 2418.6 | 99.93 | | |
| 2972.1 | 116.73 | 3000 | 56.84 | 2334.3 | 78.39 | 3000 | 79.63 | | |
| 3000 | 115.85 | | | 3000 | 59.92 | | | | |

**Table H1 Depth-Area Relation for 4-hour for Top 15 Storms in Hong Kong (Sheet 2 of 3)**

| 5-Nov-1993 | | 20-May-2015 | | 15-Aug-2015 | | 4-Jun-1997 | | 22-Jul-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) |
| 3 | 278.31 | 0.3 | 277.06 | 0.6 | 252.07 | 0.9 | 254.1 | 6.9 | 255.34 |
| 47.1 | 260.36 | 4.5 | 261.33 | 4.2 | 237.79 | 8.7 | 235.26 | 36.3 | 239.05 |
| 182.7 | 243.81 | 13.8 | 244.7 | 18 | 217.01 | 21.6 | 221.35 | 67.8 | 226.72 |
| 311.1 | 230.92 | 40.2 | 221.78 | 43.8 | 199.3 | 45.3 | 202.26 | 96.9 | 214.81 |
| 421.2 | 219.65 | 80.4 | 204.15 | 89.4 | 179.33 | 76.2 | 186.2 | 141.3 | 198.16 |
| 525 | 208.38 | 177.3 | 180.57 | 175.2 | 158.48 | 110.4 | 170.83 | 216.3 | 176.87 |
| 633.9 | 196.15 | 246.9 | 168.61 | 324.9 | 136.8 | 151.8 | 154.66 | 317.1 | 156.15 |
| 781.2 | 180.38 | 337.8 | 153.37 | 591.3 | 114.37 | 219.6 | 133.49 | 475.8 | 132.91 |
| 932.4 | 165.29 | 460.2 | 135.55 | 936.3 | 95.02 | 486.3 | 92.76 | 805.2 | 103.42 |
| 1208.1 | 141.35 | 774.6 | 104.78 | 1419 | 75.2 | 1226.4 | 59.67 | 1506 | 72.14 |
| 1701.6 | 110.65 | 1340.4 | 76.59 | 2475.3 | 47.31 | 2402.7 | 35.61 | 2572.8 | 46.09 |
| 3000 | 69.08 | 2387.1 | 47.38 | 3000 | 37.62 | 3000 | 27.38 | 3000 | 39.16 |
| | | 3000 | 36.94 | | | | | | |

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**Table H1 Depth-Area Relation for 4-hour for Top 15 Storms in Hong Kong (Sheet 3 of 3)**

| 11-May-2014 | | 2-Jul-1997 | | 7-Oct-2015 | | 8-May-1992 | | 25-Jun-2008 | |
|---|---|---|---|---|---|---|---|---|---|
| Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) | Area ($km^2$) | Depth (mm) |
| 0.3 | 252.91 | 9 | 231.19 | 3.9 | 232.44 | 1.2 | 229.34 | 1.8 | 228.66 |
| 10.2 | 234.16 | 35.1 | 216.85 | 12.3 | 219.16 | 15.9 | 209.82 | 18 | 213.28 |
| 40.2 | 216.91 | 64.2 | 203.47 | 22.8 | 204.12 | 59.7 | 193.38 | 81.9 | 190.25 |
| 193.5 | 189.7 | 102 | 188.28 | 35.7 | 188.6 | 151.8 | 173.62 | 357 | 167.73 |
| 418.8 | 175.11 | 153.6 | 170.89 | 63.3 | 165.32 | 343.8 | 152.24 | 666 | 153.86 |
| 699.9 | 160.59 | 297.6 | 142 | 106.8 | 143.51 | 777.9 | 130.01 | 1039.2 | 138.71 |
| 886.8 | 150.45 | 534.9 | 117.51 | 174.9 | 121.37 | 1200 | 114.8 | 1636.5 | 119.66 |
| 1054.2 | 140.47 | 820.2 | 98.1 | 247.5 | 103.96 | 1816.8 | 97.03 | 2163.3 | 105.75 |
| 1224 | 129.61 | 1225.8 | 78.19 | 382.8 | 79.86 | 2676.9 | 77.97 | 2656.2 | 93.44 |
| 1727.7 | 101.3 | 2016.3 | 51.18 | 1629.6 | 21.52 | 3000 | 71.56 | 3000 | 84.3 |
| 3000 | 63.31 | 3000 | 30.85 | 3000 | 10.87 | | | | |

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