Developments in deriving Precipitation Frequency and PMP in China Mainland

--Key issues of engineering hydrology

Prof. Bingzhang Lin
lbz@nuist.edu.cn

应用水文气象研究院(AHMRI) – Bridging Science and Society (BSS)
水文气象学院(COHM) – Education for Future (EFF)
南京信息工程大学 (NUIST)

A courtesy visit to Taiwan CWB

Taipei, Taiwan

13 January, 2016

What are the key issues in Engineering Hydrologic Studies?

--Hydrologic frequency & PMP estimation in China Mainland

100 years of AMS rainfall data at a station in the U.S.

- (011901) 28-4229 ANMAX
- 100

3.46	2.60	5.65	4.90	3.02	7.15	2.97	2.86	2.70	3.18
3.39	2.13	2.34	2.61	4.39	2.04	3.06	3.92	3.00	3.67
1.97	1.45	2.78	2.73	3.98	1.98	2.17	2.00	1.80	2.08
1.72	2.61	3.10	3.73	2.82	2.17	2.10	6.78	6.05	4.55
1.92	3.20	3.50	3.45	2.78	3.33	1.42	2.62	3.23	4.20
2.42	3.23	2.22	4.25	3.21	4.02	1.37	4.16	1.81	5.05
2.44	3.84	2.80	2.29	3.35	3.18	5.06	2.41	3.58	2.10
4.29	3.80	3.78	6.63	2.77	3.42	2.25	2.71	2.84	2.35
2.83	1.90	2.63	2.46	4.68	4.10	2.51	1.95	2.59	4.71
4.94	3.88	2.81	2.51	2.85	3.72	2.91	2.26	4.88	2.63

100 years of AMS rainfall data

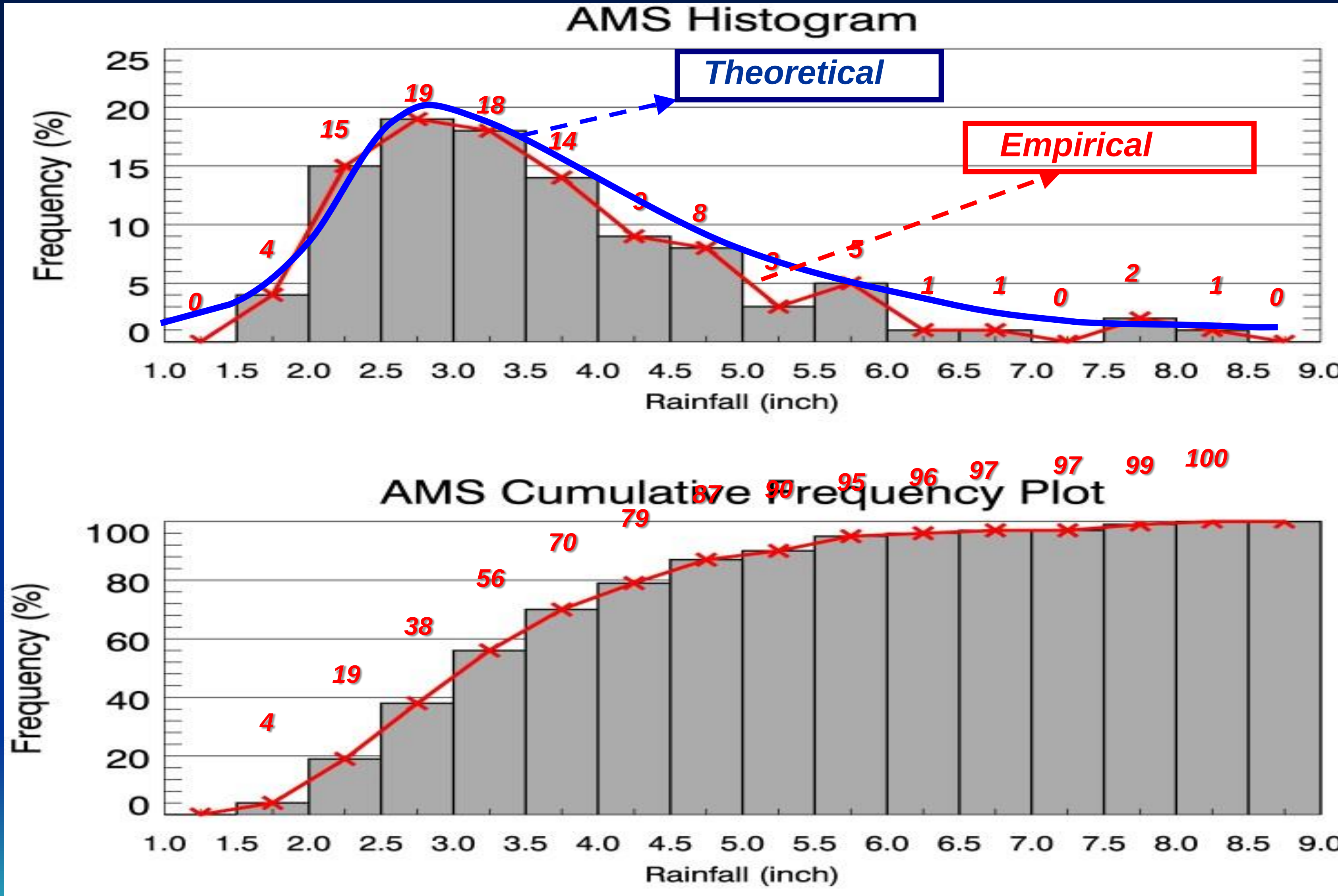
（Sorted + Grouped）

(011901) 28-4229 ANMAX

100

1.55	1.61	1.64	1.95	2.04	2.05	2.15	2.18	2.21	2.23
2.25	2.27	2.31	2.36	2.38	2.38	2.42	2.46	2.46	2.52
2.55	2.56	2.60	2.65	2.66	2.73	2.74	2.77	2.79	2.85
2.85	2.94	2.95	2.96	2.96	2.97	2.98	2.98	3.06	3.07
3.10	3.14	3.15	3.15	3.18	3.19	3.20	3.21	3.22	3.23
3.24	3.30	3.37	3.40	3.42	3.47	3.52	3.61	3.61	3.63
3.64	3.66	3.66	3.78	3.80	3.84	3.88	3.91	3.92	3.97
4.06	4.16	4.22	4.23	4.29	4.31	4.35	4.40	4.45	4.51
4.56	4.65	4.72	4.76	4.82	4.86	4.98	5.16	5.31	5.34
5.53	5.56	5.60	5.73	5.74	6.41	6.86	7.52	7.69	8.11

No.	Interval	Number	Frequency	Cumulative
1	0.01 – 0.50	0	0.0	0.0
2	0.51 – 1.00	0	0.0	0.0
3	1.01 – 1.50	0	0.0	0.0
4	1.51 – 2.00	4	0.4	0.4
5	2.01 – 2.50	15	0.15	0.19
6	**2.51 – 3.00**	19	**0.19**	0.38
7	3.01 – 3.50	18	0.18	0.56
8	3.51 – 4.00	14	0.14	0.70
9	4.01 – 4.50	9	0.09	0.79
10	4.51 – 5.00	8	0.08	0.87
11	5.01 – 5.50	3	0.03	0.90
12	5.51 – 6.00	5	0.05	0.95
13	6.01 – 6.50	1	0.01	0.96
14	6.51 – 7.00	1	0.01	0.97
15	7.01 – 7.50	0	0.0	0.97
16	7.51 – 8.00	2	0.02	0.99
17	8.01 – 8.50	1	0.01	1.00



(直方图 Increment = 0.5 in)

$$F(x)=\int_{-\infty}^{+\infty} f(x)dx=\int_{a}^{b} f(x)dx=\int_{?}^{?} f(x)dx=1$$

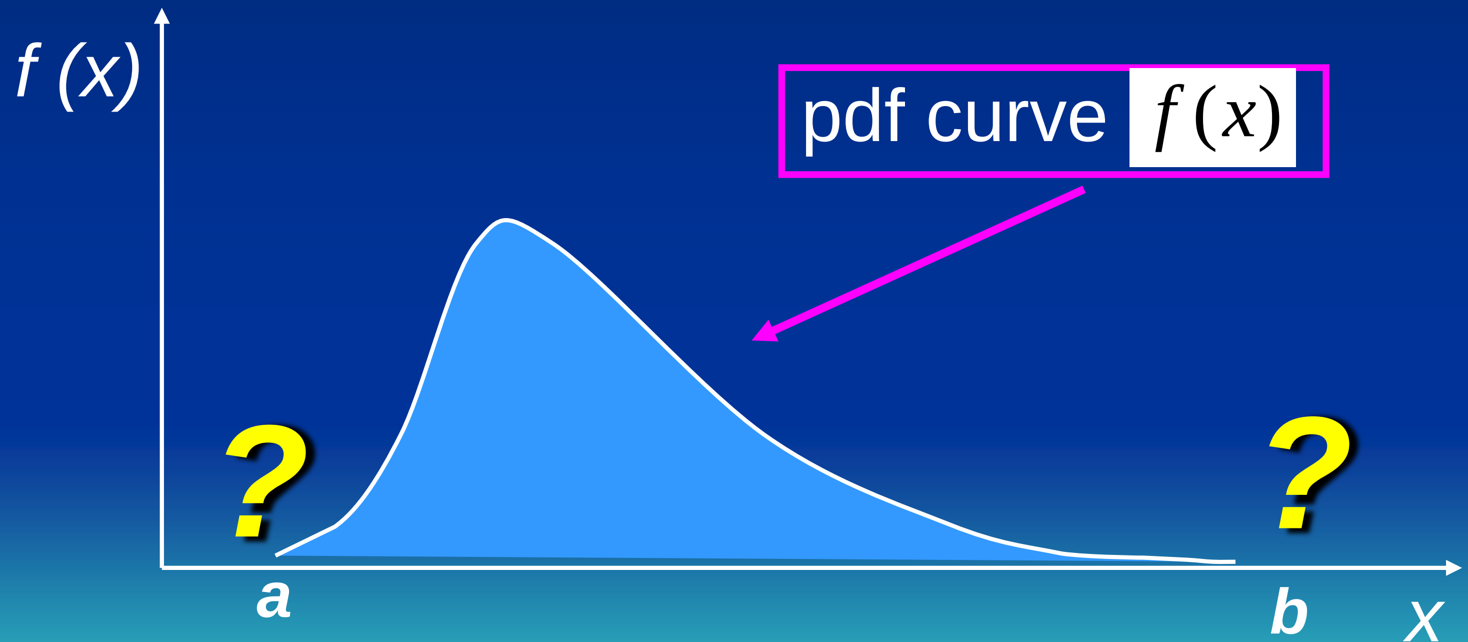


Fig. 2 Probability density function curve

What is Frequency Analysis ?

Frequency Analysis -- is a statistical approach using sample or samples to estimate the population probability distribution.

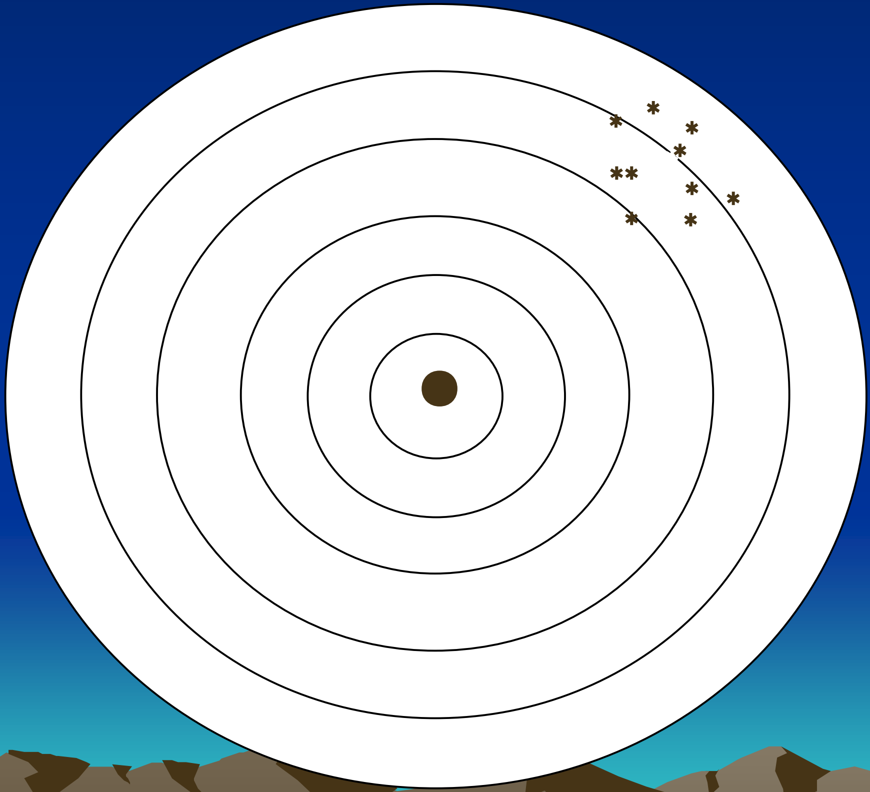
频率计算是一种利用一个或数个样本来推求总体概率分布的统计方法。（样本 → 总体）

What are the Essential Issues of FA?

1. Precision
2. Accuracy

Nature of the Frequency Analysis (1)

- Like shooting practice: Precision and Accuracy (e.g. firing 10 shots)



Good precision

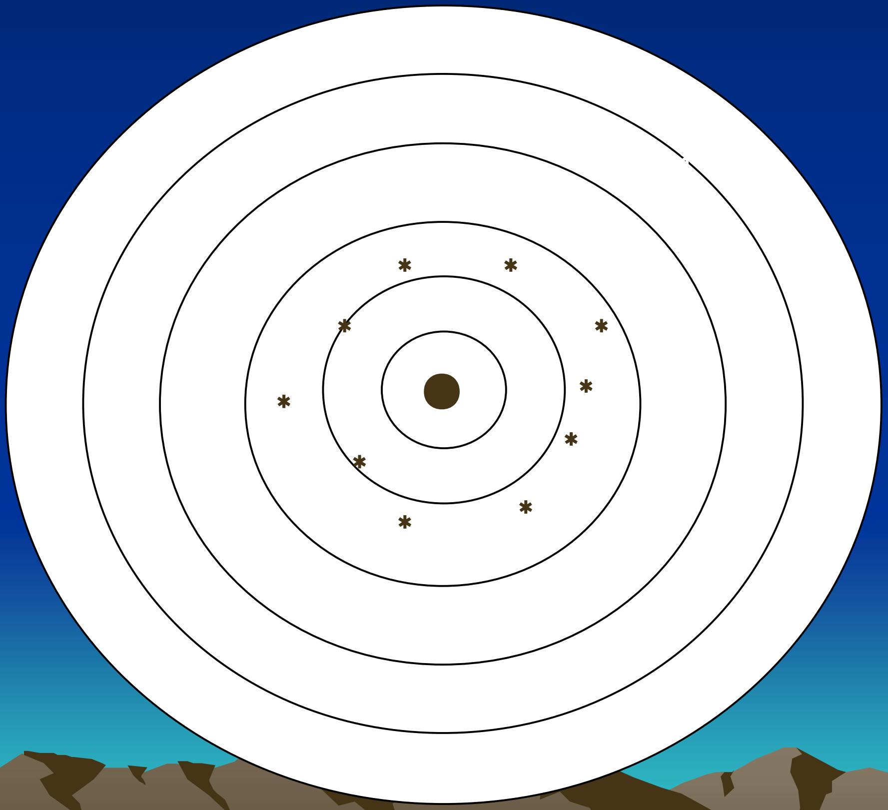
（精度好）

Poor accuracy

（准确度差）

Nature of the Frequency Analysis (2)

- Like shooting practice: Precision and Accuracy



Poor precision

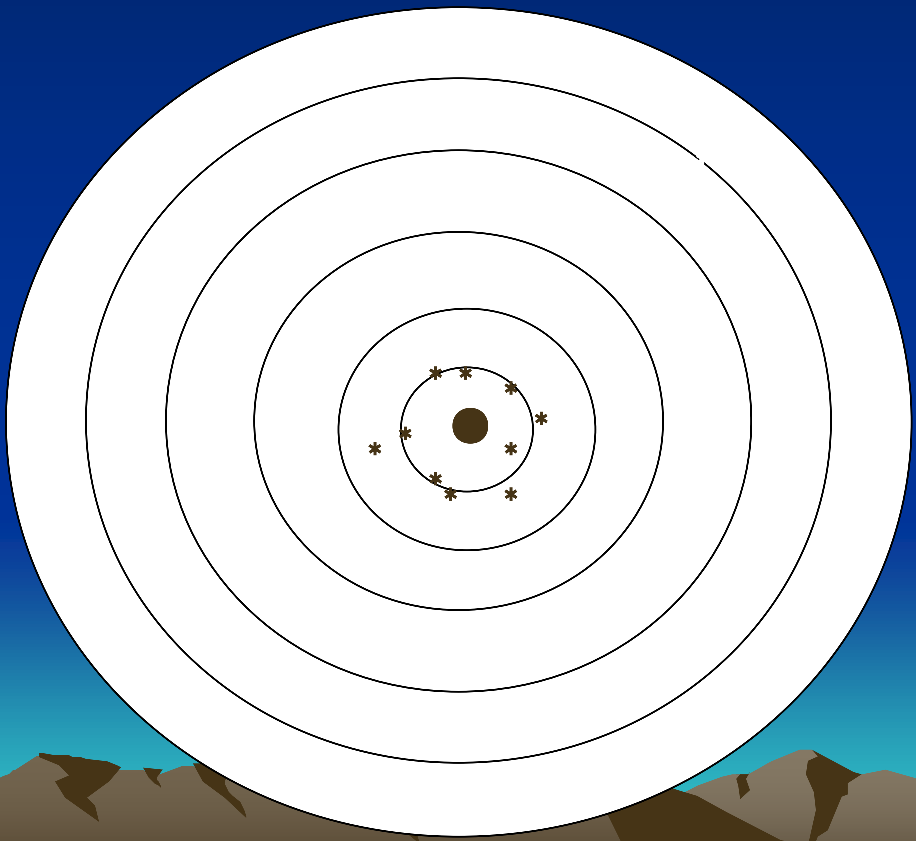
（精度差）；

Moderate accuracy

（准确度还可以）

Nature of the Frequency Analysis (3)

- Like shooting practice: Precision and Accuracy



Good precision

（精度好）；

Good accuracy

（准确度好）

Two Impossible Things in FA
（水文频率分析有 两大难题）

1. Theoretical true value of frequencies is unknown forever. (100-year ?)

   -- 真值永远不知道！

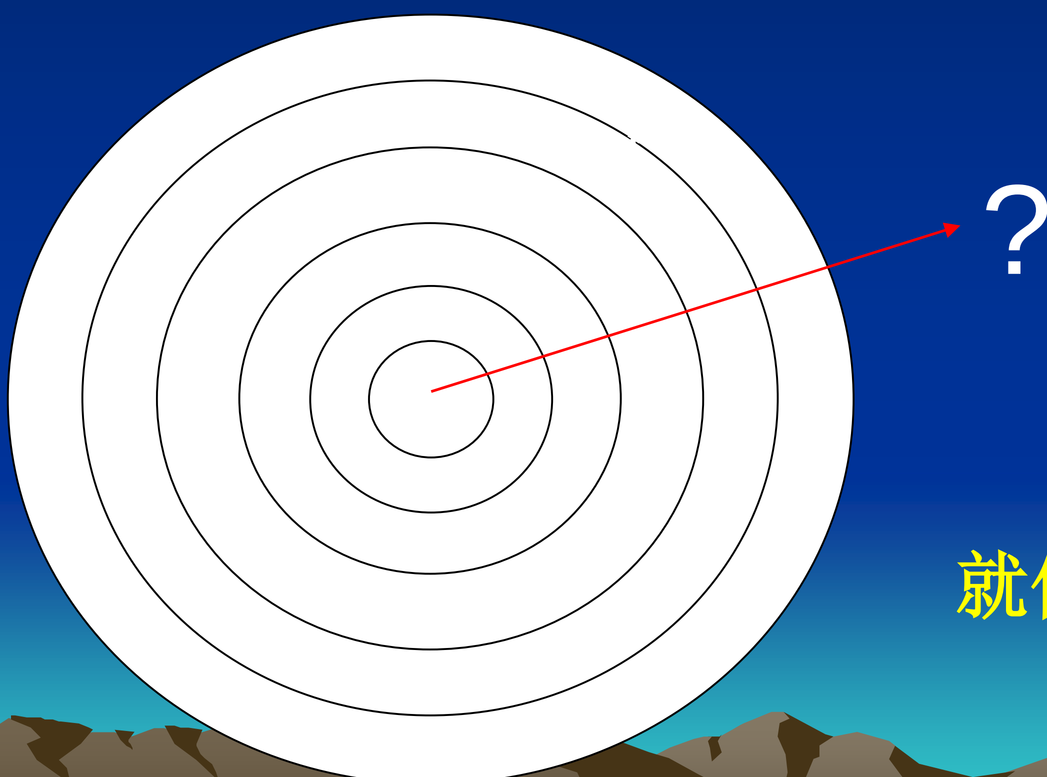
2. There is no analytical way to derive a theoretical distribution to best fit the data. (GLO or GEV or PE3 ?)

   -- 无法从理论上推导出分布函数！

Where is the bull's-eye?

（就像打靶时不知靶心在何处！）

- The true value of frequencies such as 100-year is unknown forever.



Something like bulls-eye unknown while shooting.

就像打靶时靶心不明!

Global Climate Change Makes the Issue more Complicated

Let data talk!

Location of Daily Stations in OH Study Area

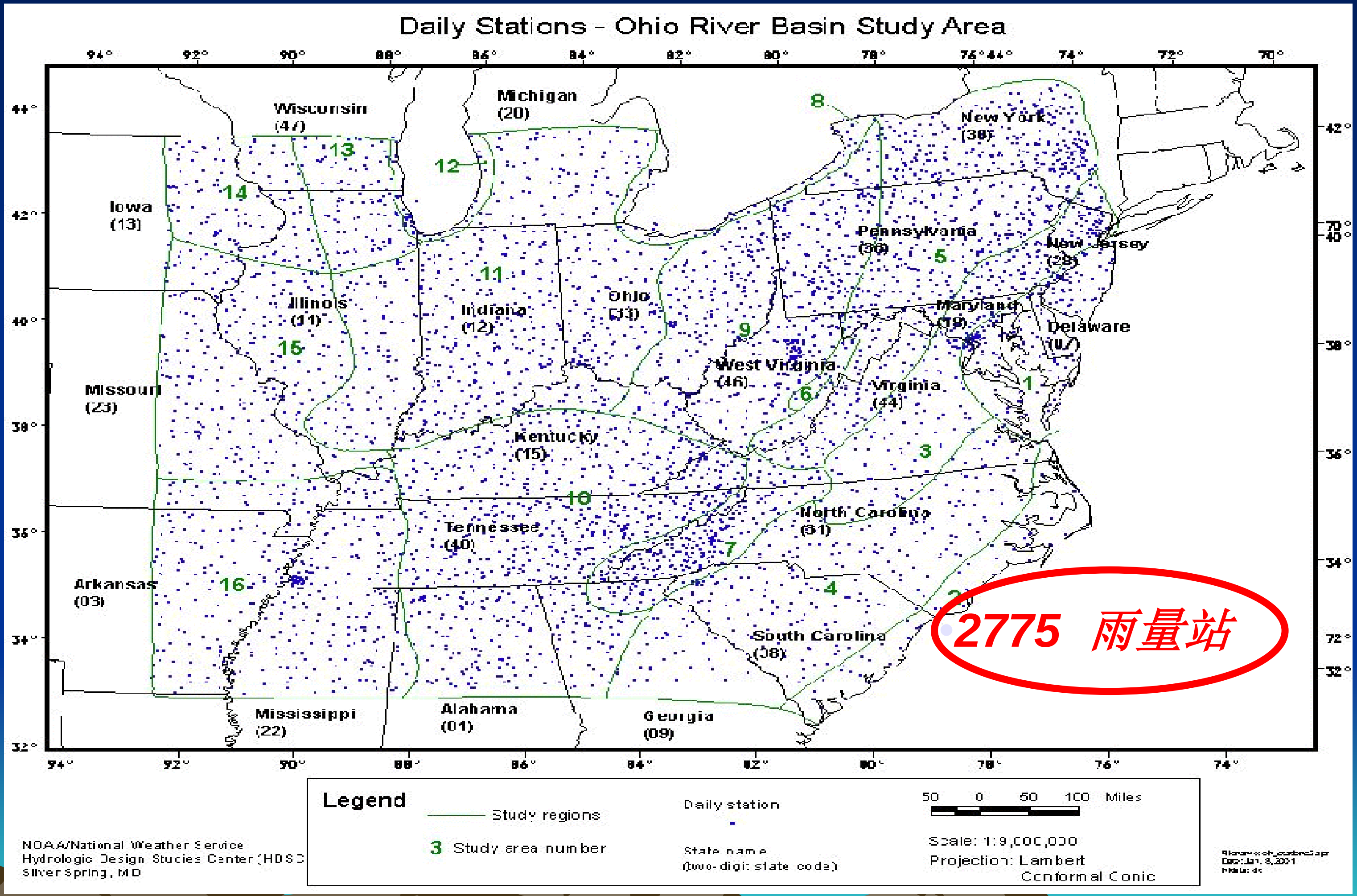


Fig. 3 Location of raingauges in Ohio River Basin

Investigation of 1,741 daily AMS in Mainland China

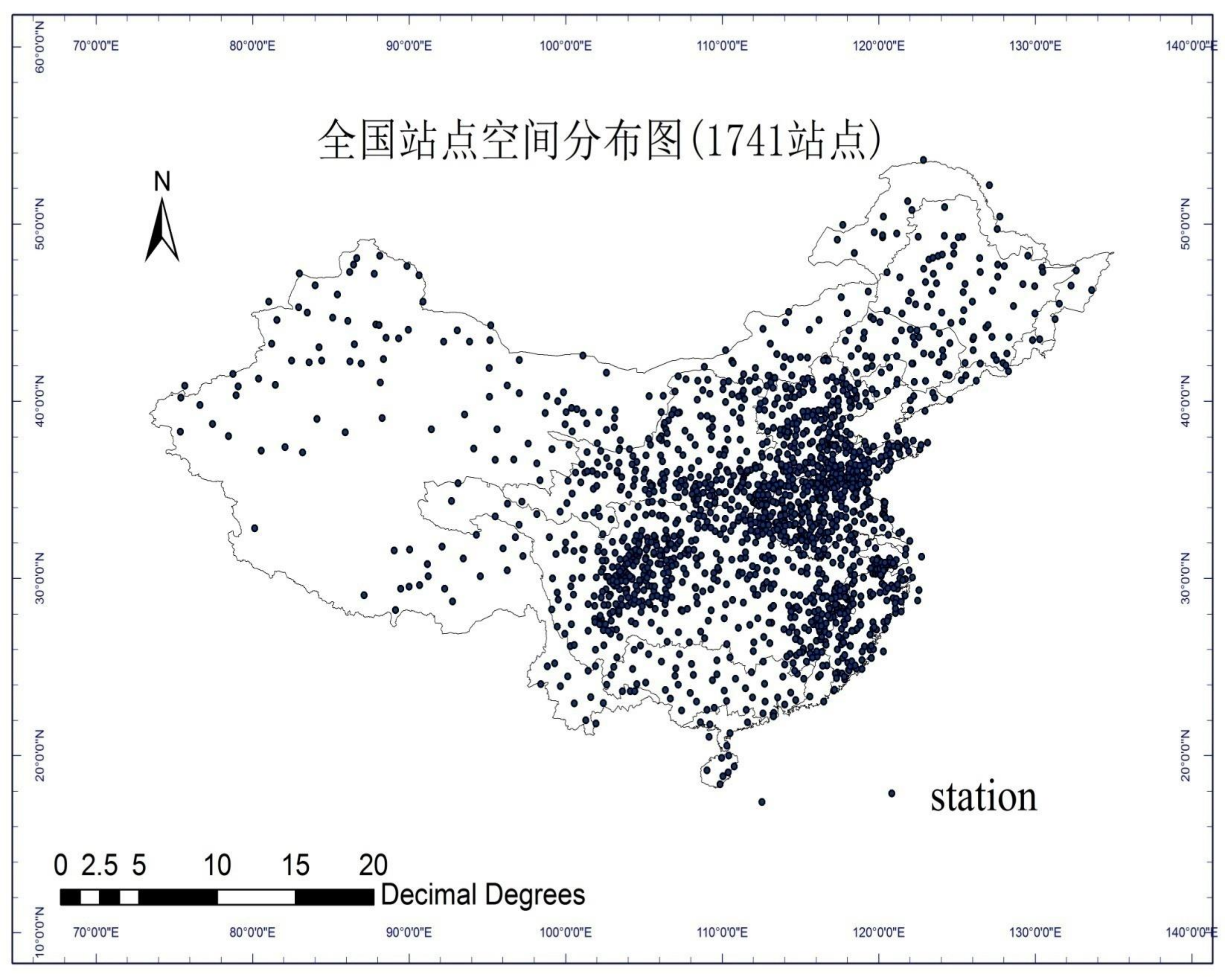


Fig. 6 Location of raingauges in China (partially)

Findings

- **Generally speaking，there was no obvious linear trend and shift in mean for daily AMS in Ohio of the U.S. and in China in the past century；**

（总的来说，中美两国地区（流域）年最大日雨量均值在过去的近一百年中没有明显的趋势性和跳跃性；）

- **However，there was more than *50%* of tested sites that exhibited a clear increase in variance of daily AMS in OH River Basin，with SD increased by 23% for the latter half- to the former half- century。--- *What does it imply？***

（但是，有**50%**被检验的美国俄亥俄流域的资料中，其方差呈现明显的增长趋势，上世纪后半叶的雨量极值系列的标准差（**SD**）较之上半叶平均增加了**23%**。**--** *这意味著什么呢？*）

It implies:

We may observe **more and more** extreme hydrometeorological events (**droughts or floods**) in the Ohio River Basin area in the near future than before though their mean does not change. ***So the world***.

这意味著在不久的未来，人们在俄亥俄流域将会碰到越来越多的极端水文气象事件（干旱、洪涝）。世界的其他地方也可能如此。

Facing with the acceleration of climate change,

What is our job？

One of Our Mission

Exploration of a *Robust* (稳健) *and Reliable* (可靠）Approach to Precipitation frequency Analysis of Extreme Events – foundation for rick analysis。

（探索一种稳健、可靠的频率估算法 – 风险分析的基础。）

What we should/can do? (1)

L-Moments Method – focusing on the issue of ***precision*** in terms of parameter estimation

Methods of Parameter Estimation

1. Conventional Moments Method (CMM)

$$M_{p,0,0} = E[X^p] = \int_0^1 x^p dF(x)$$

Power shift

Advantage – Linearity

2. L-Moments Method (LMM)

$$M_{1,r,0} = E[X\{F(X)^r\}] = \int_0^1 x\{F(x)\}^r dF(x)$$

L-Moments

Definition: L-moments are expectations of certain linear combinations of order statistics (Hosking, 1989) （线性矩：次序统计量线性组合的期望值）

$$\lambda_r \equiv r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E[X_{r-k:r}], \qquad r = 1,2,\ldots$$

$$\lambda_1 = EX$$

$$\lambda_2 = \frac{1}{2} E(X_{2:2} - X_{1:2})$$

$$\lambda_3 = \frac{1}{3} E(X_{3:3} - 2X_{2:3} + X_{1:3})$$

$$\lambda_4 = \frac{1}{4} E(X_{4:4} - 3X_{3:4} + 3X_{2:4} - X_{1:4})$$

$(When \quad X_{1:n} \le X_{2:n} \le \cdots \le X_{n:n})$

Application of RLM to Precipitation Frequency Analysis in the U.S.

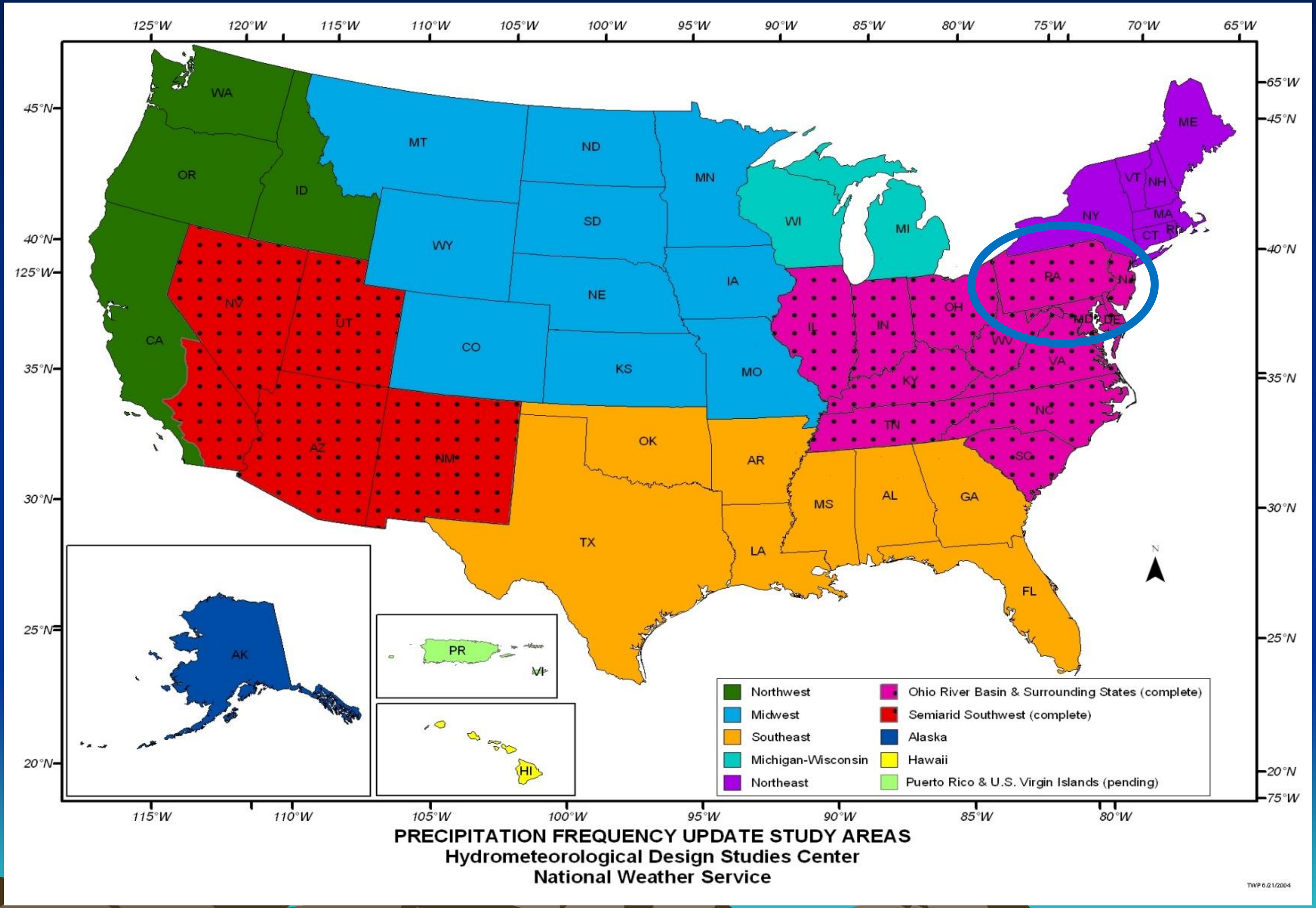
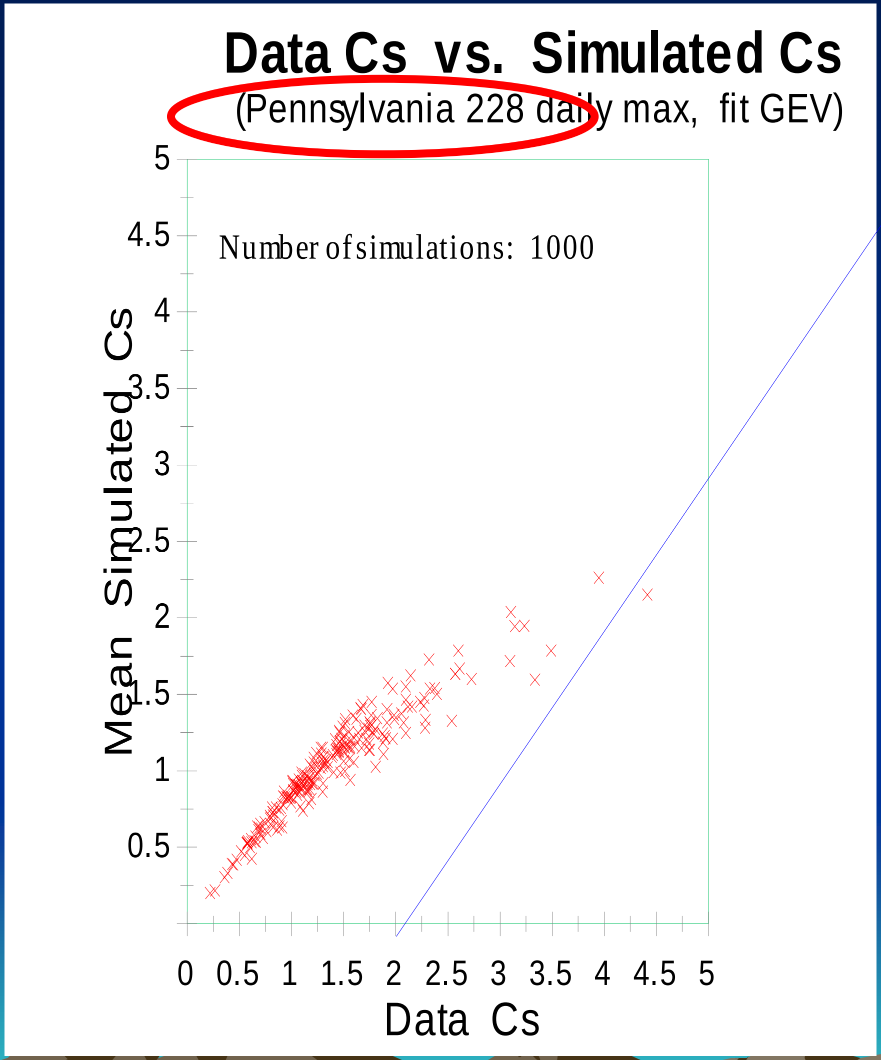
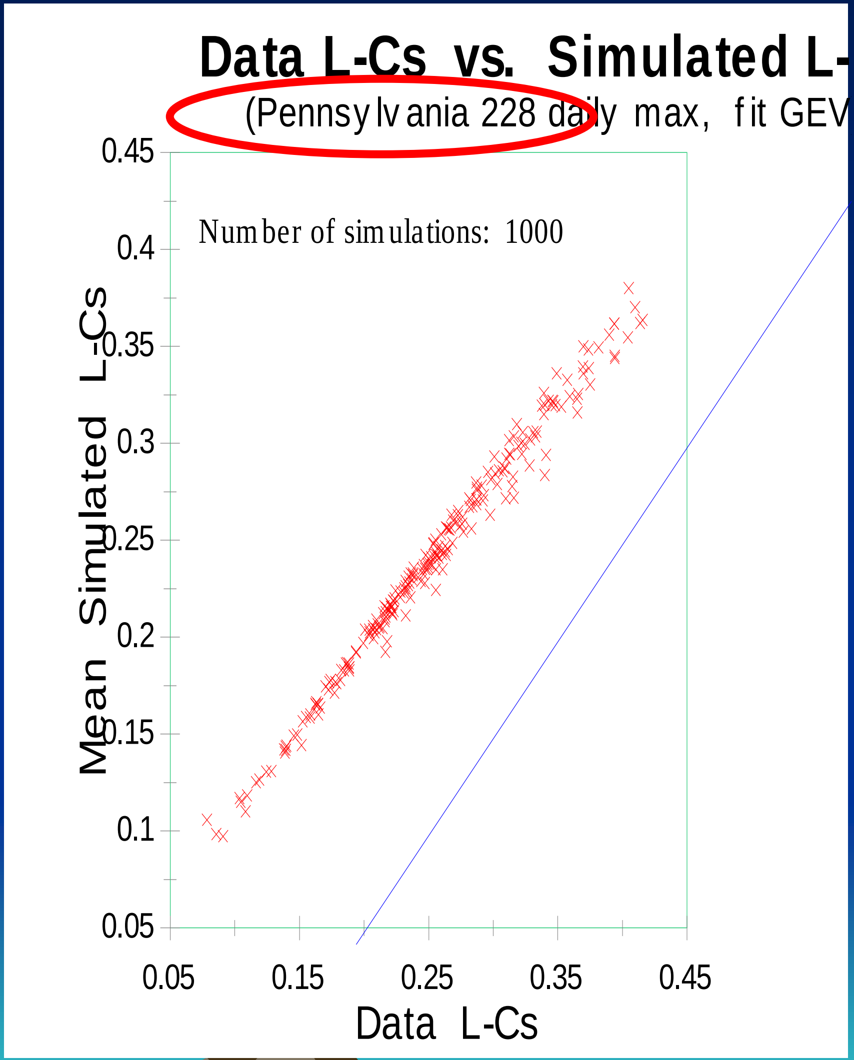


Fig. 9 Pennsylvania data will be used for comparison

Comparison of CMM to LMM on Biasedness





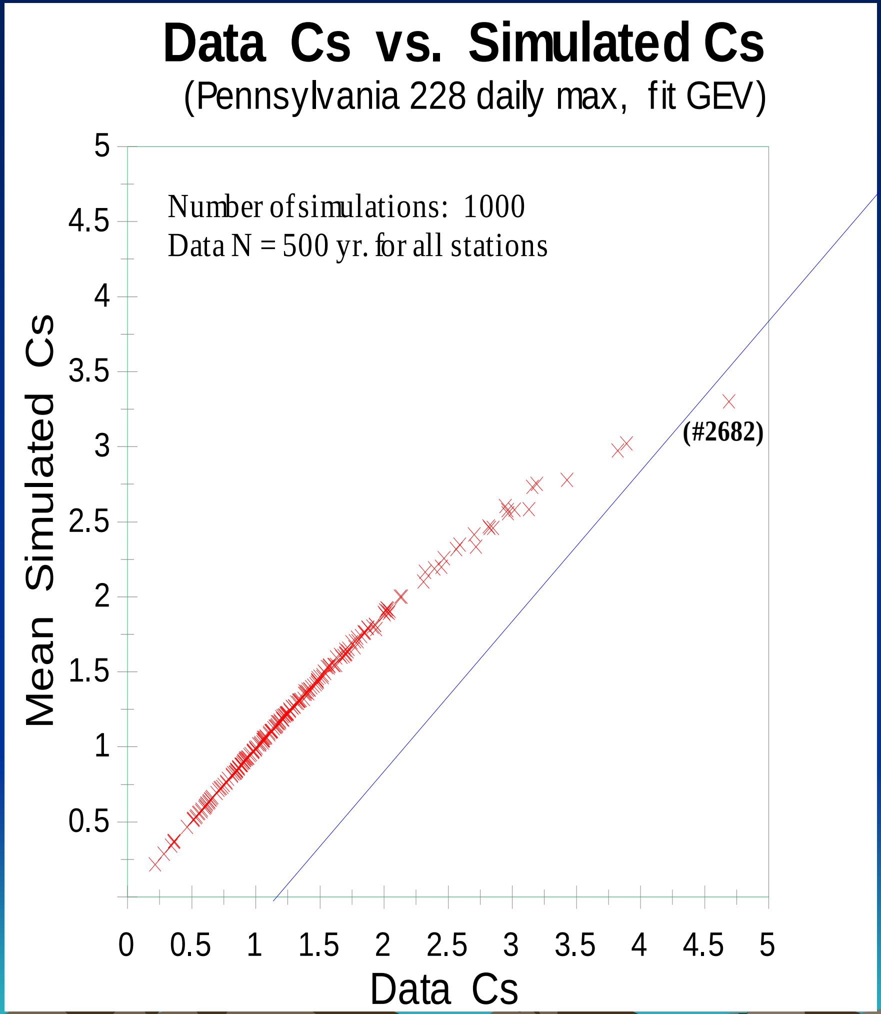
High biasedness of Cs **Much less biasedness of L-Cs**

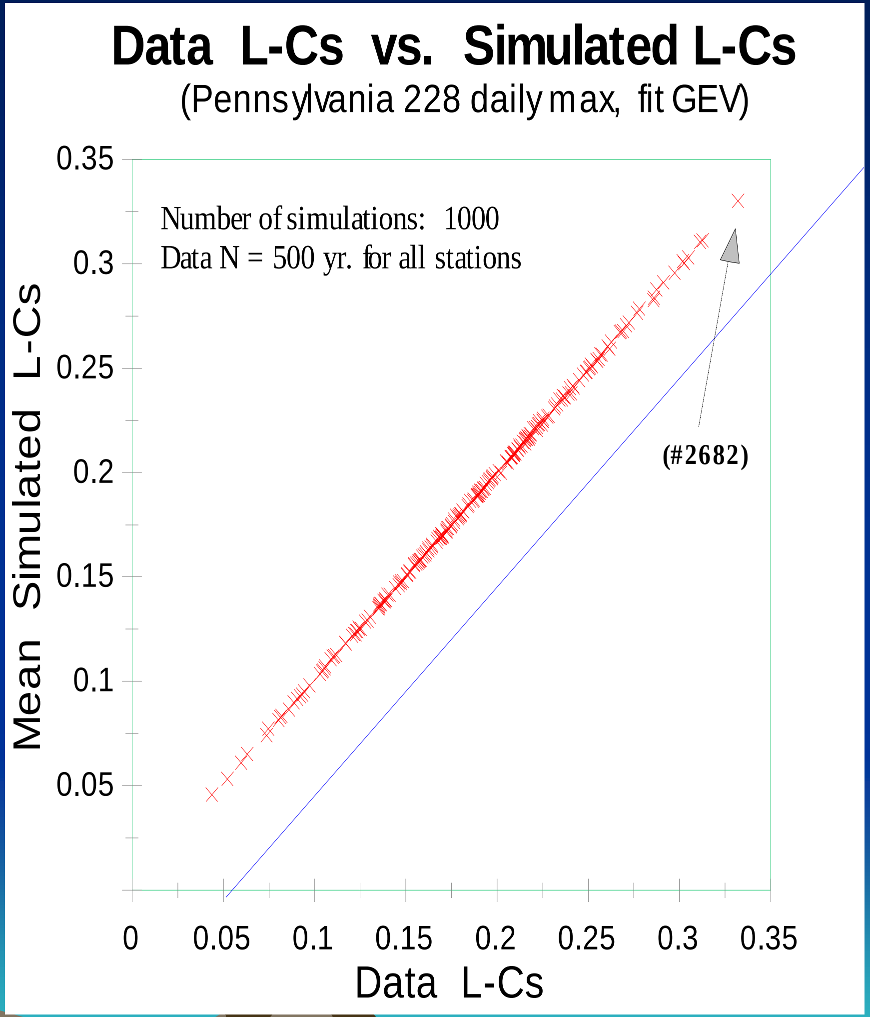
Fig. 10 Comparison for biasedness between CMM and LMM based on PA data

Comparison of CMM to LMM on Robustness

CMM plays poorly to outlier (10.37"/day on 7/22/1947 at #2682, PA)

Cs cannot model this outlier even for N = 500 yr.





CMM: poor modeling to outlier **LMM: very well modeling to outlier**

Fig. 11Comparison for robustness between CMM and LMM based on PA data

The same findings on biasedness and robustness have been drawn for annual AMS precipitation data in China Mainland.

Regional L-moments Analysis in China

(A pilot study – Application to Taihu Lake Basin)

Fig. 12 Location of Taihu Lake Basin

(96+45) Sites of Taihu Lake divided into 8 HGS Regions

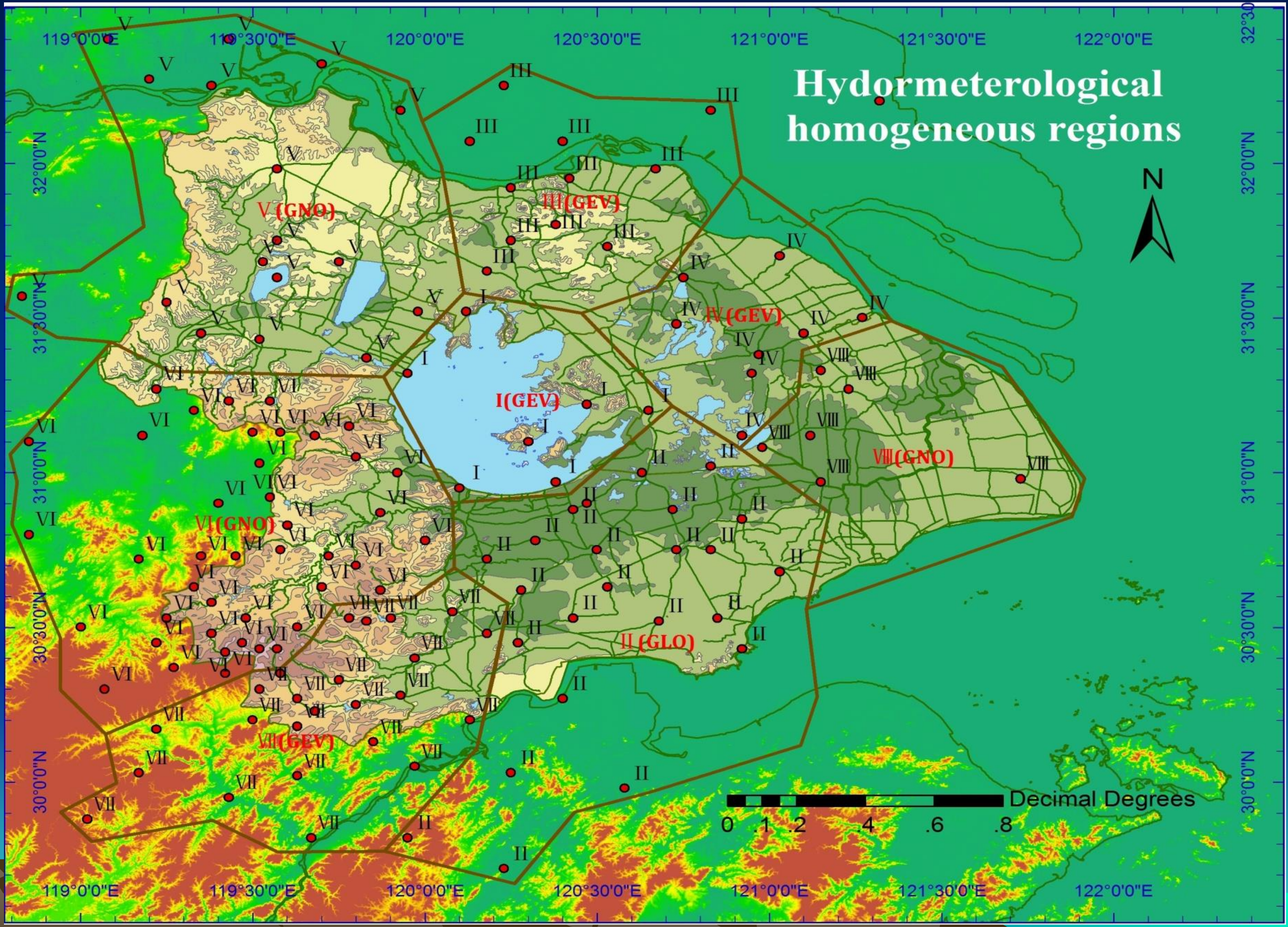


Fig. 14 Regionalization of Taihu Lake Basin

Comparison for Taihu Lake Data (1) on Biasedness

Taihu 96 daily max, fit GLO

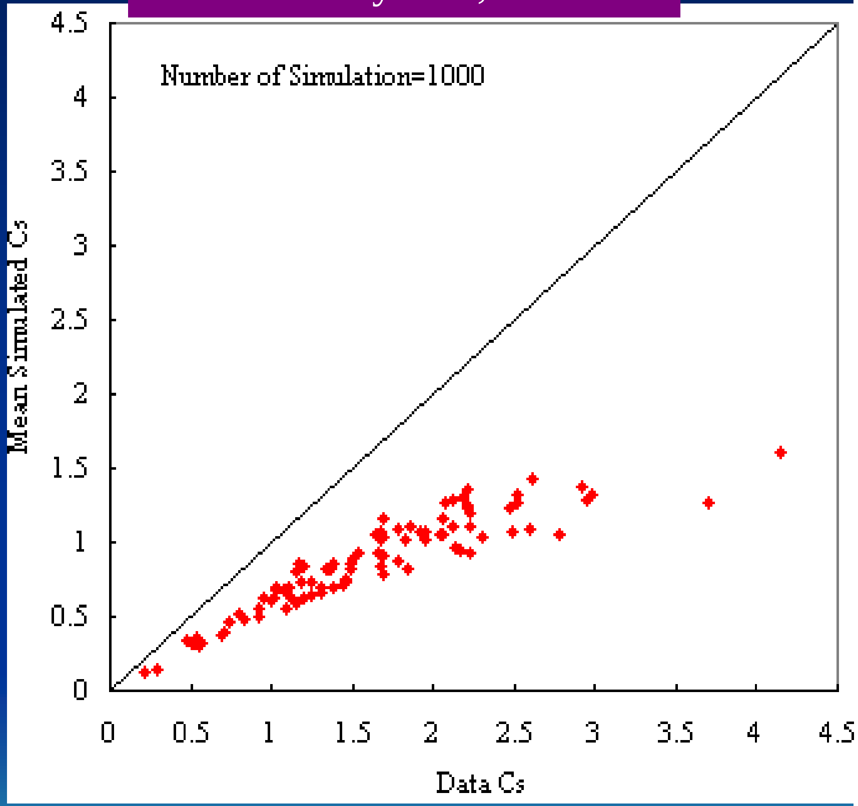


Fig.1 Biasedness on skewness of CMM

Taihu 96 daily max, fit GLO

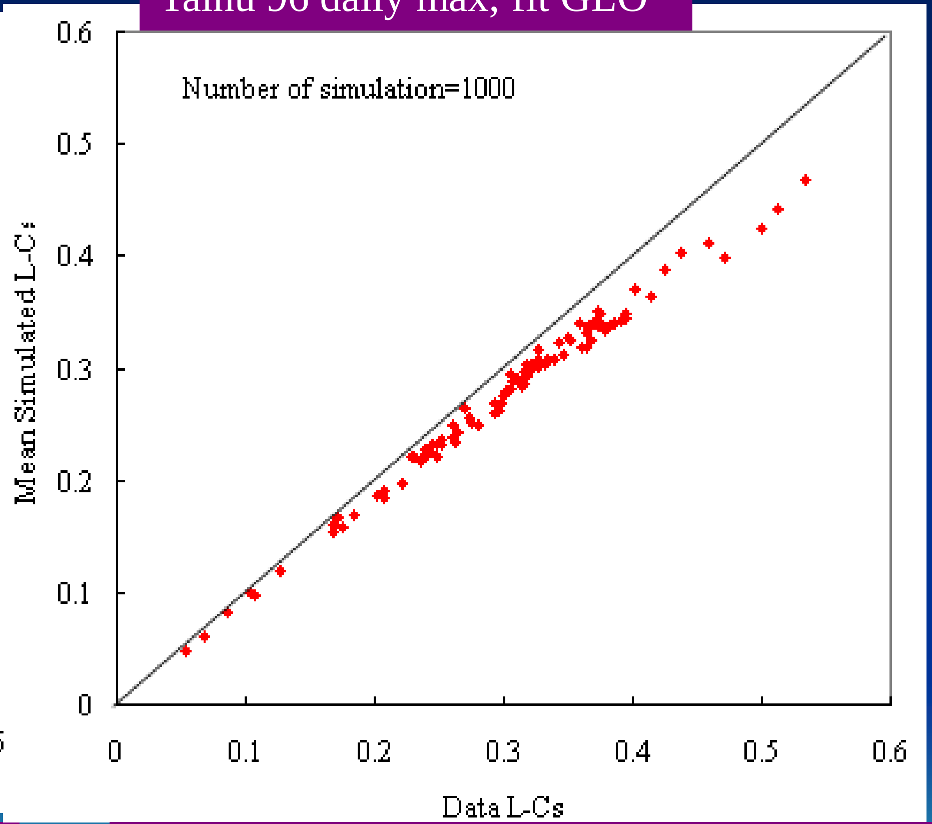


Fig.2 Unbiasedness on skewness of LMM

Fig. 15 Comparison for biasedness between CMM and LMM based on Taihu data

Comparison for Taihu Lake Data (2) on Robustness

Taihu 96 daily max, fit GLO

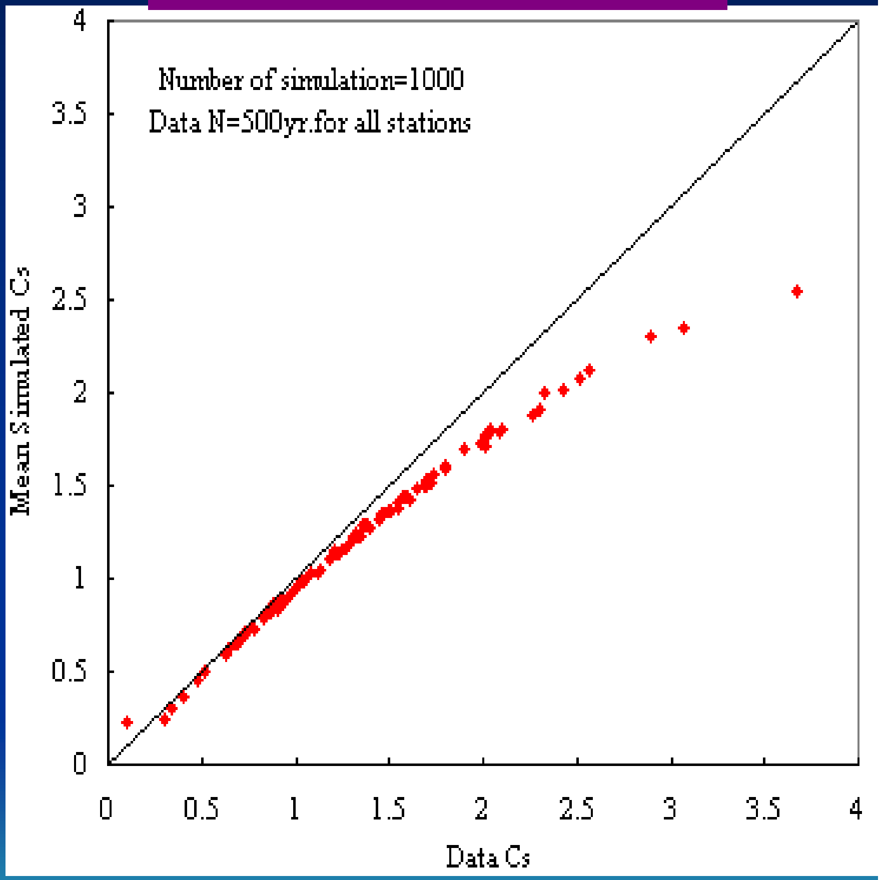


Fig.3 Difficult to model the outlier by CMM

Taihu 96 daily max, fit GLO

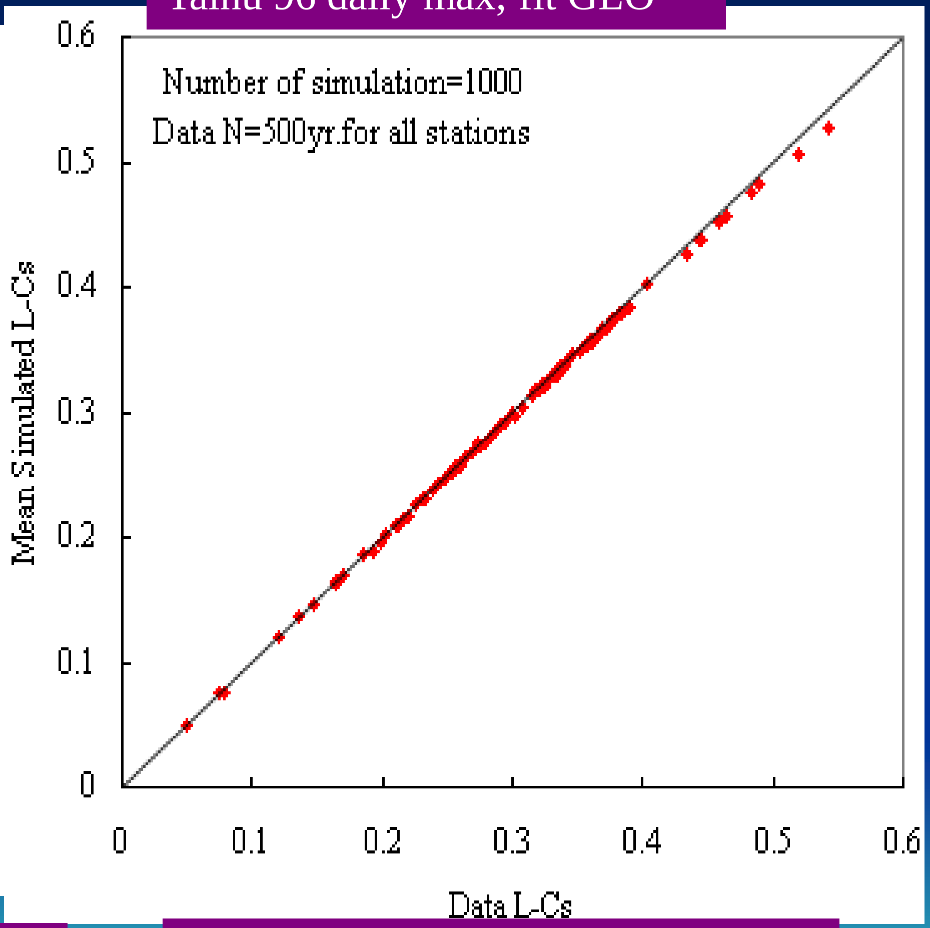


Fig.4 Robustness to outlier by LMM

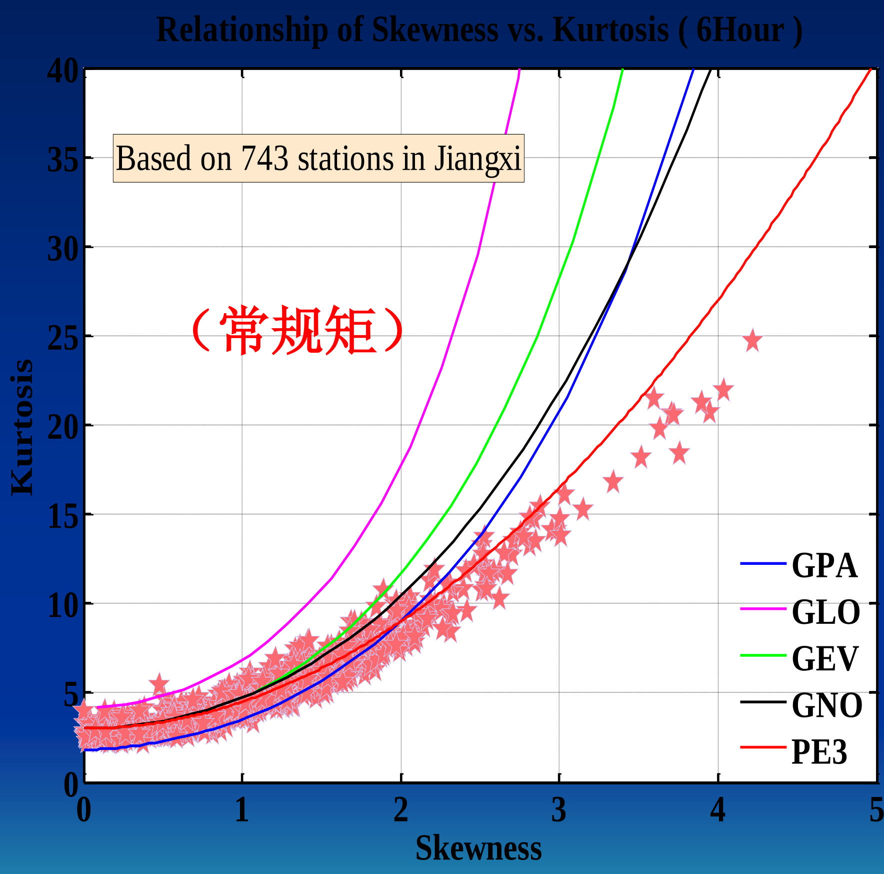
Fig. 16 Comparison for robustness between CMM and LMM based on Taihu data

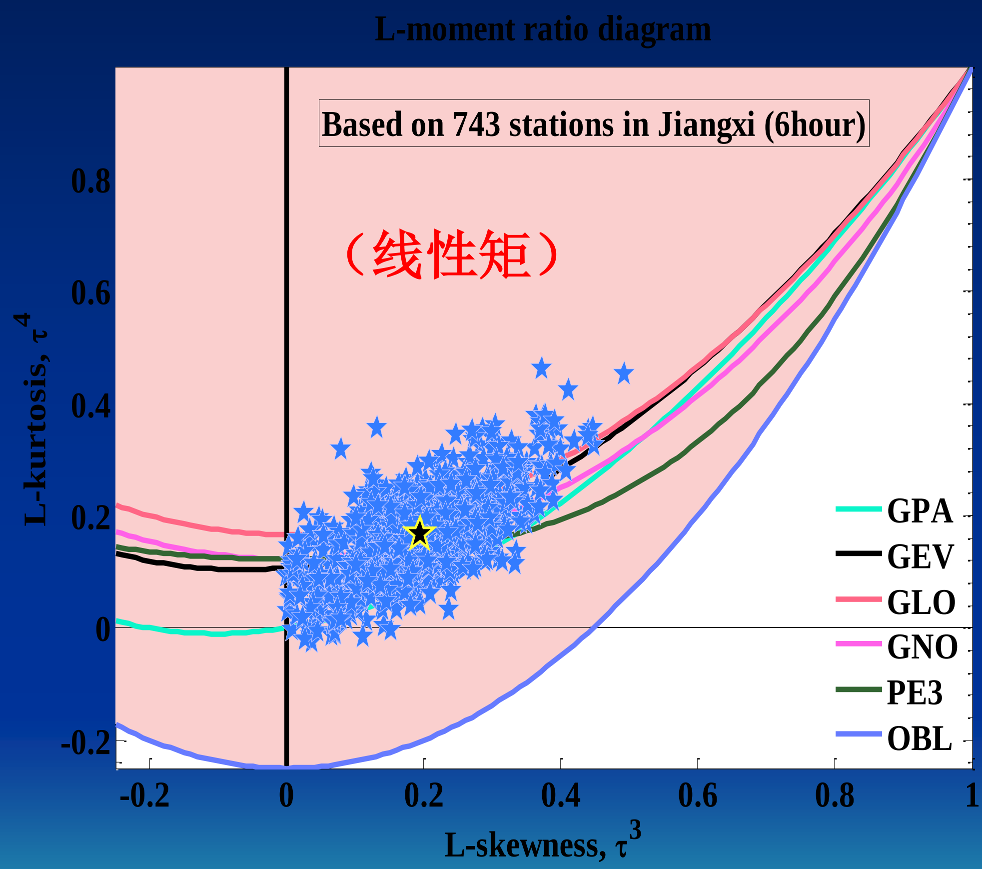
More comparisons

- CMM is less sensitive to screen the data than the LMM does in terms of statistical characteristics.
- The *Pearson Type III* has been officially selected for fitting data (rainfall & streamflow) in China Mainland while the CMM has widely been adopted in design studies in China Mainland since 1950'.

PE3 is the best-fit while CMM was used

（Jiangxi 江西省, China）





PE3 is the best-fit when CMM was used (1-1)

（Ohio River Basin)

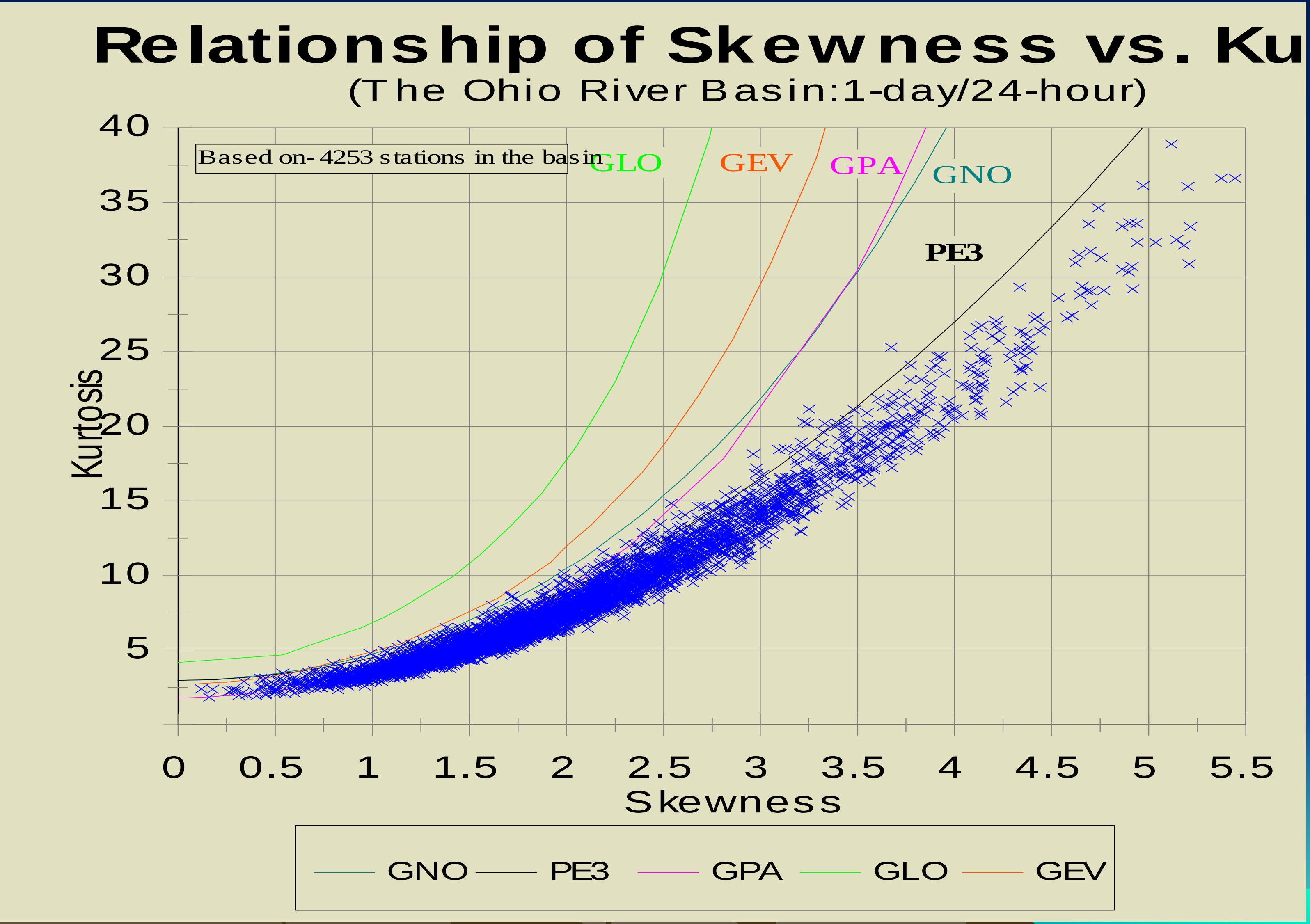


Fig. 17 Diagram of Cs vs. Ck for daily stations in the OH area (all points)

PE3 is the best-fit when CMM used (1-2)
(Ohio River Basin)

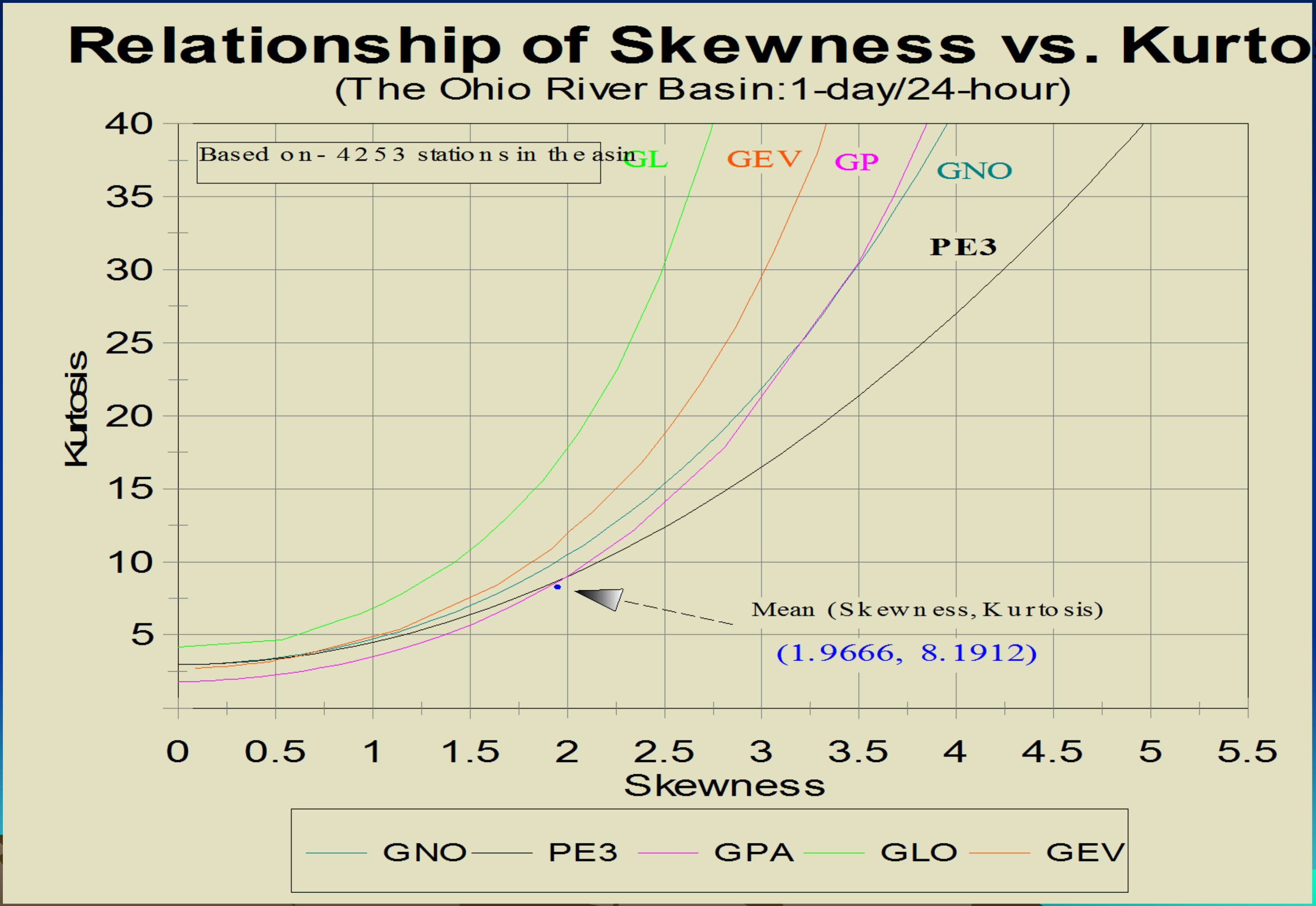


Fig. 18 Diagram of Cs vs. Ck for daily stations in the OH area (mean point)

GEV is the best-fit when LMM used (2-1)
(Ohio River Basin)

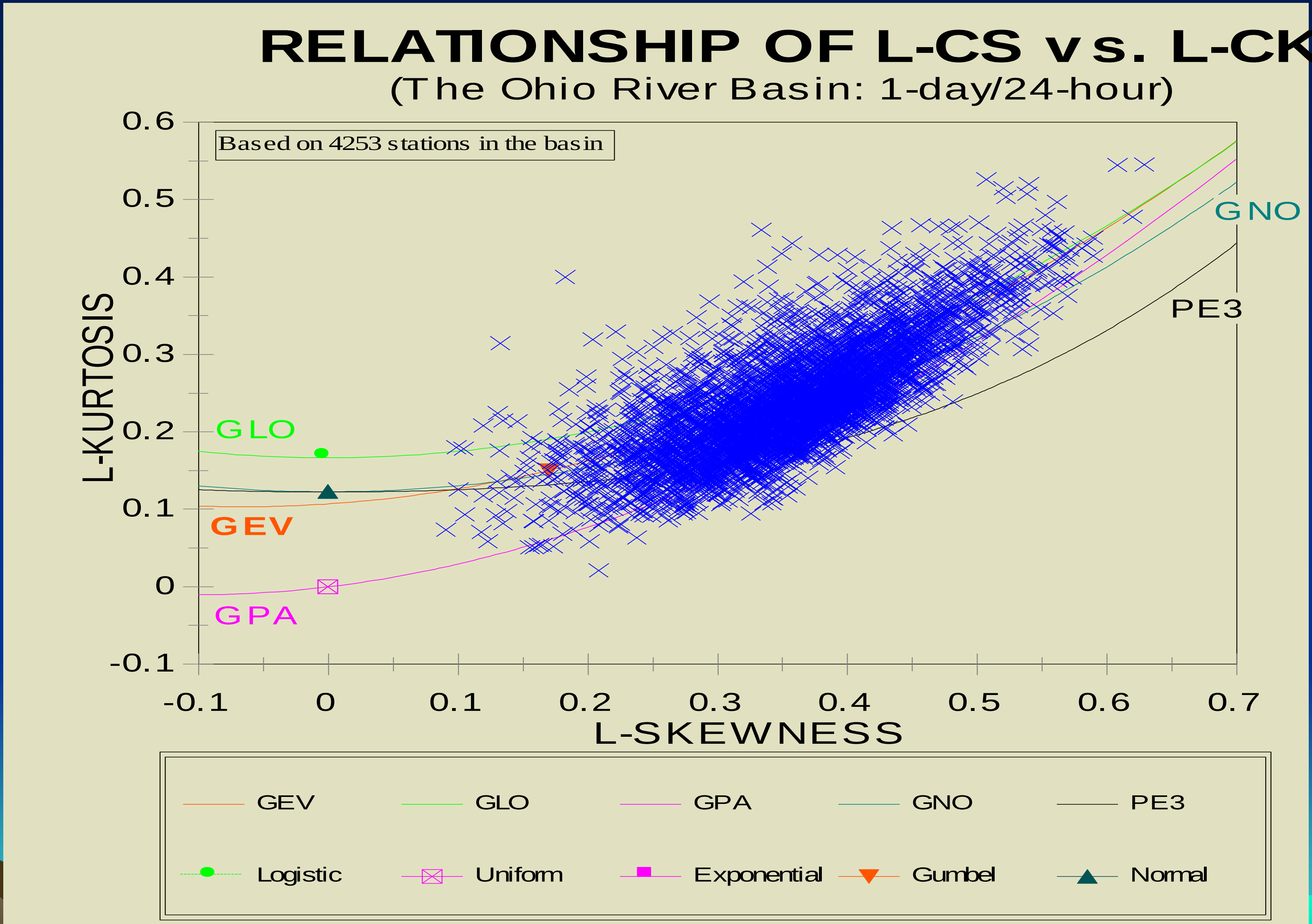


Fig. 19 Diagram of L-Cs vs. L-Ck for daily stations in the OH area (all points)

GEV is the best-fit when LMM used (2-2)
(Ohio River Basin)

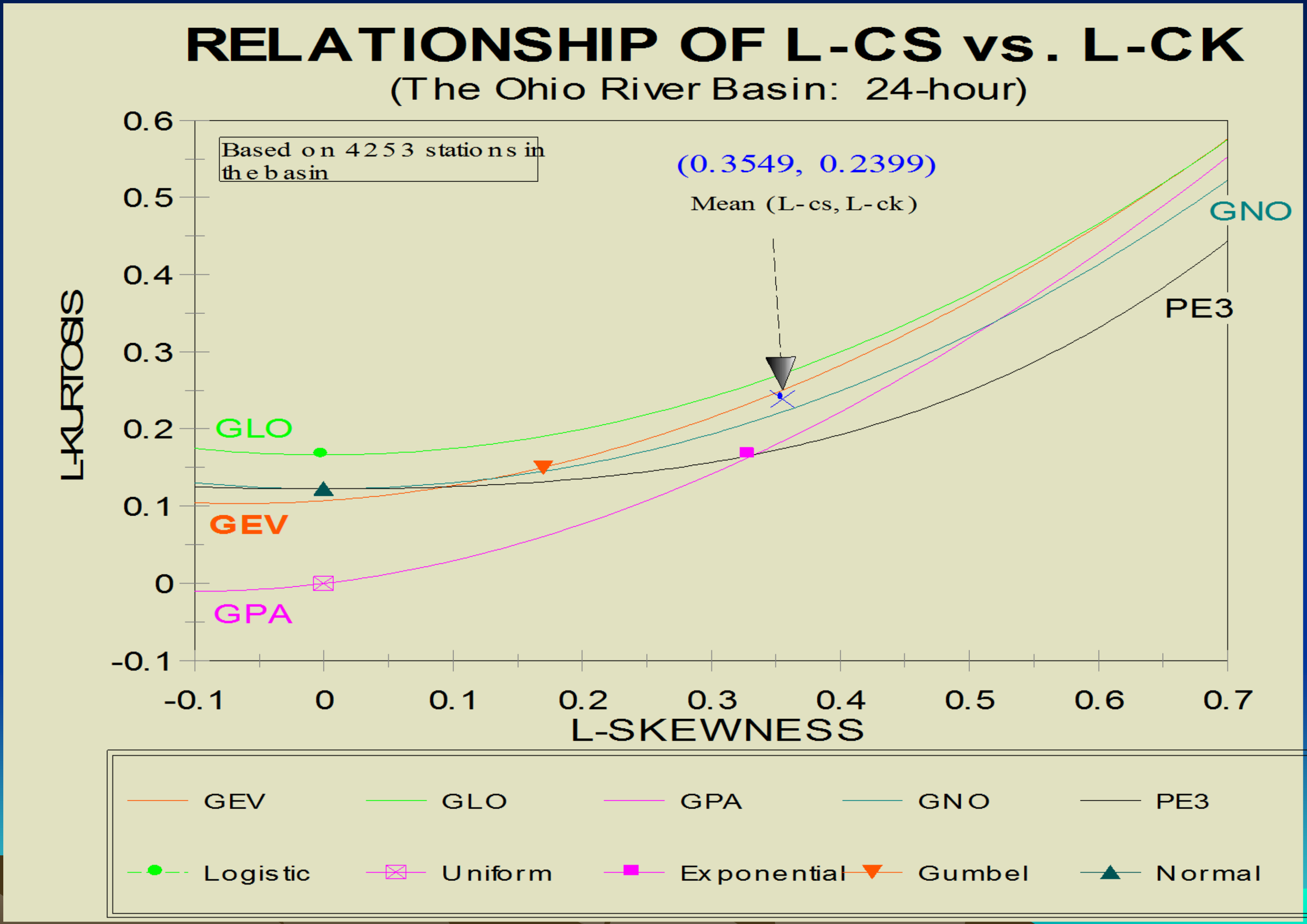


Fig. 20 Diagram of L-Cs vs. L-Ck for daily stations in the OH area (mean point)

What we should/can do? (2)

Regional Analysis – focusing on the issue of ***accuracy*** in terms of uncertainties of quantiles

Regionalization – Homogeneous Regions

Assume： A rainfall could be decomposed into the **regional component** reflecting the common characteristics in the region and the **local component** reflecting the individual local characteristics.

$$Q_{T,i,j} = q_{T,i} * \bar{x}_{i,j}$$

$$q_{T,i} = \frac{Q_{T,i,j}}{\bar{x}_{i,j}}$$

水文气象一致区

1. 每个雨量都可以分解成*共性分量*和*个性分量*;
2. 一致区内所有站点的共性分量是同分布的、并按资料长度加权配合一条最优的无量纲概率分布曲线;
3. 此地区无量纲分布曲线与各个站点的本地分量“叠加”，组成该站的概率分布曲线;
4. 推求各个站点的频率估计值。

Regionalization → *Reduces quantile uncertainty*

Reduced uncertainties in terms of confidence interval (Regional analysis provides more stable estimates)

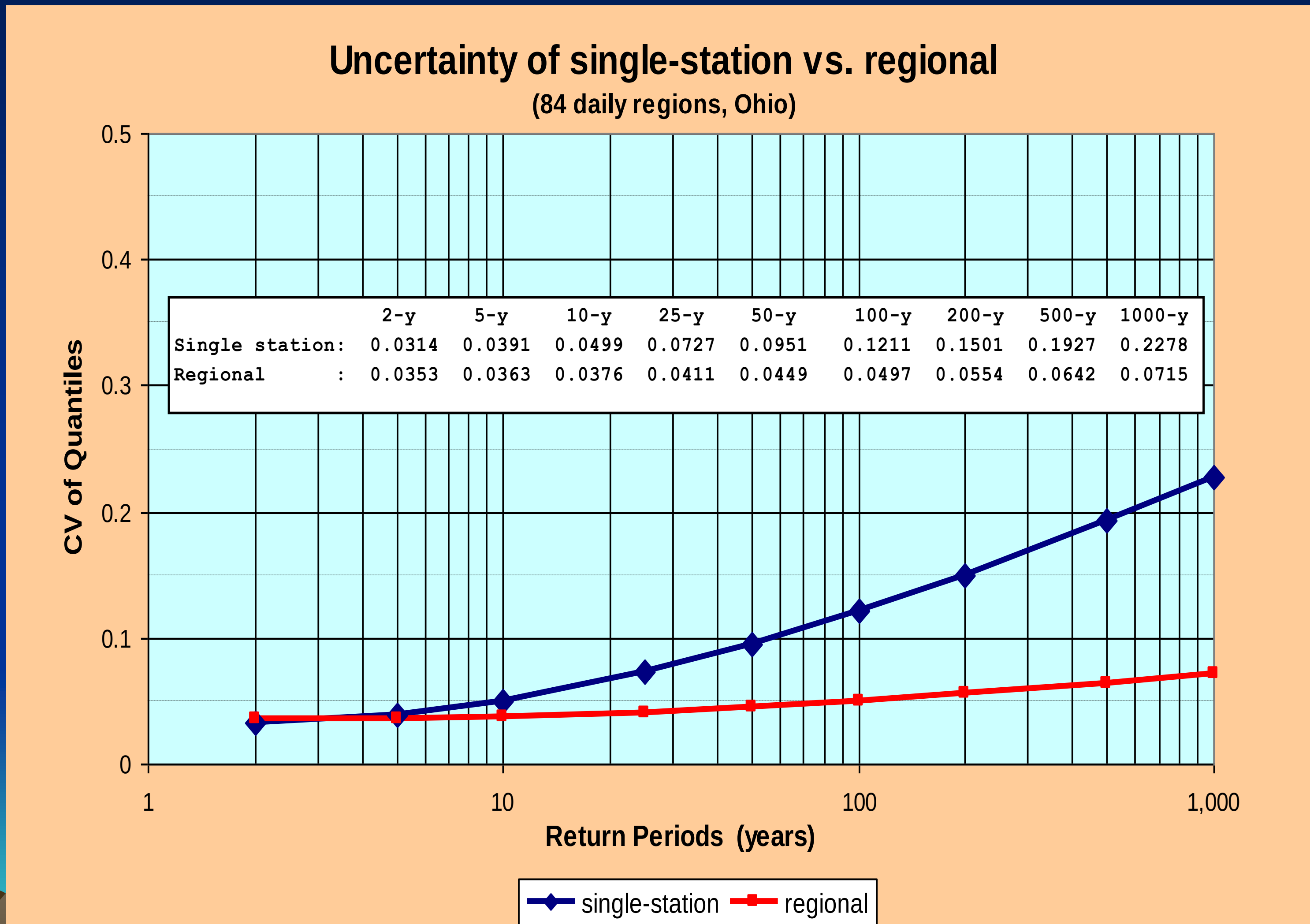


Fig. 21 Comparison for uncertainties of quantiles between the at-site FA and regional FA

中国大陆现有技术与新技术的差距

1. 现有 – *主观性强、资料信息有限*

   常规矩法 + （单点、单时段、指定单一线型）+目估适线（一点一线加双眼）

2. 新技术– *客观性强、充分利用资料信息*

   线性矩 + （地区分析、多时段、多线型比较）+准则判断

8 Relevant Topics for FA

- Advantages of the RLA (Regional L- moments Analysis)
- Criteria to identify homogeneous regions
- Goodness-of-fit
- Real-data-check
- Consistency adjustments over time & space
- Intersite dependence
- Uncertainties of quantiles – conf. intervals
- Sampling methods – AMS or PDS or AES

Online FA Deliverables (1)

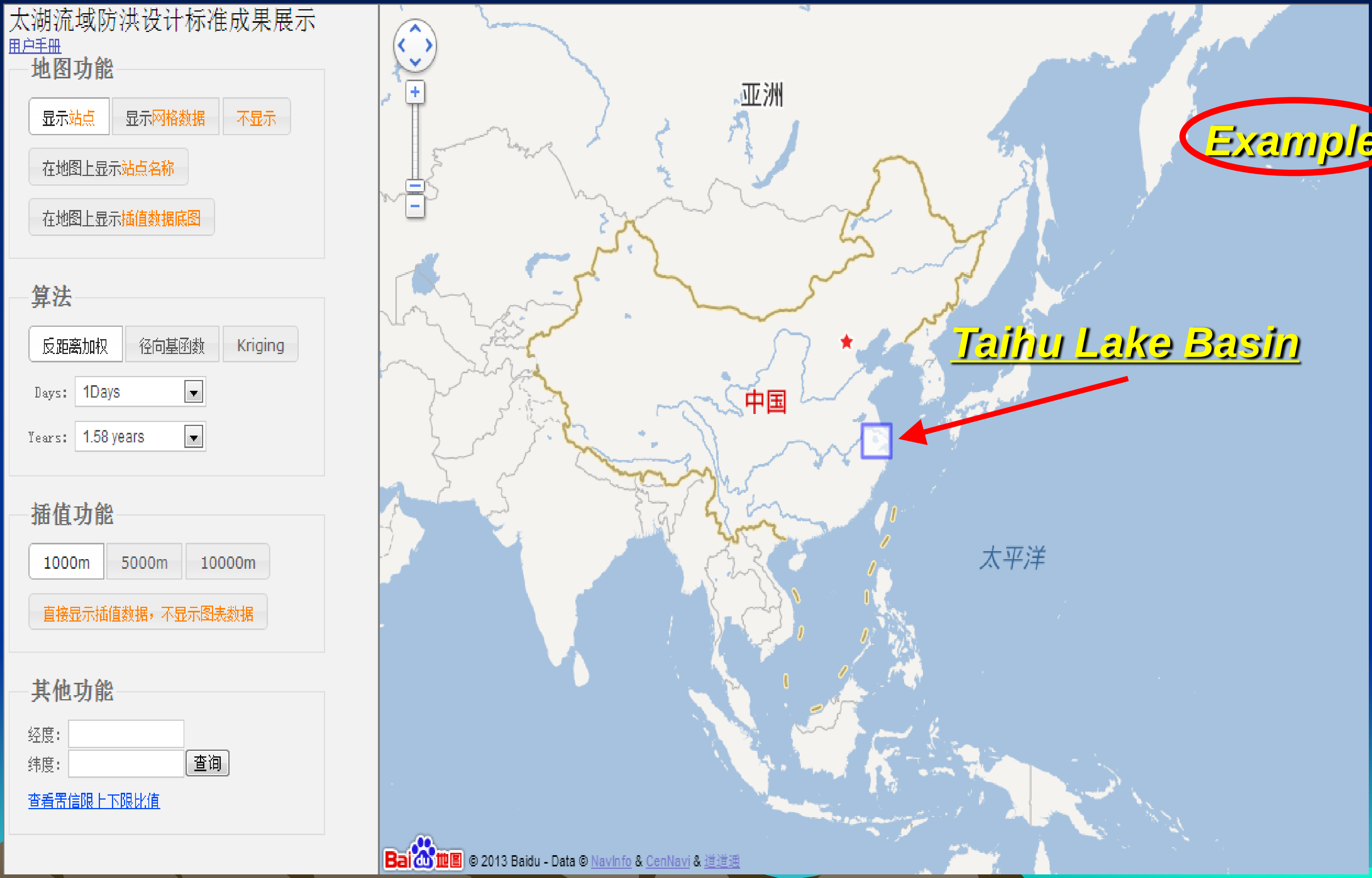
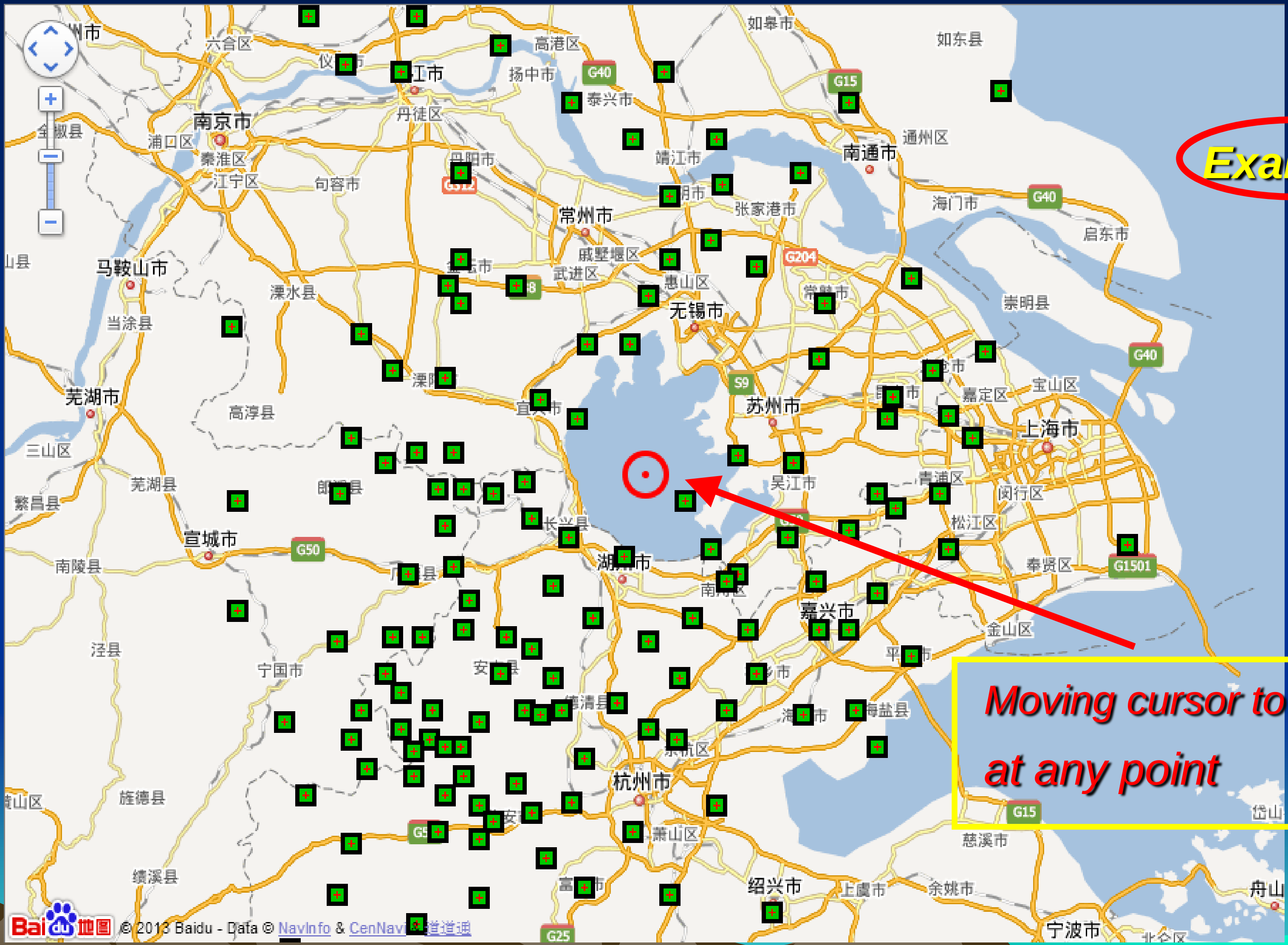


Fig. 22 Home page of online FA products for Taihu Lake Basin

Online FA Deliverables (2)



Example

Moving cursor to click at any point

Fig. 23 Online FA products for Taihu Lake Basin (1)

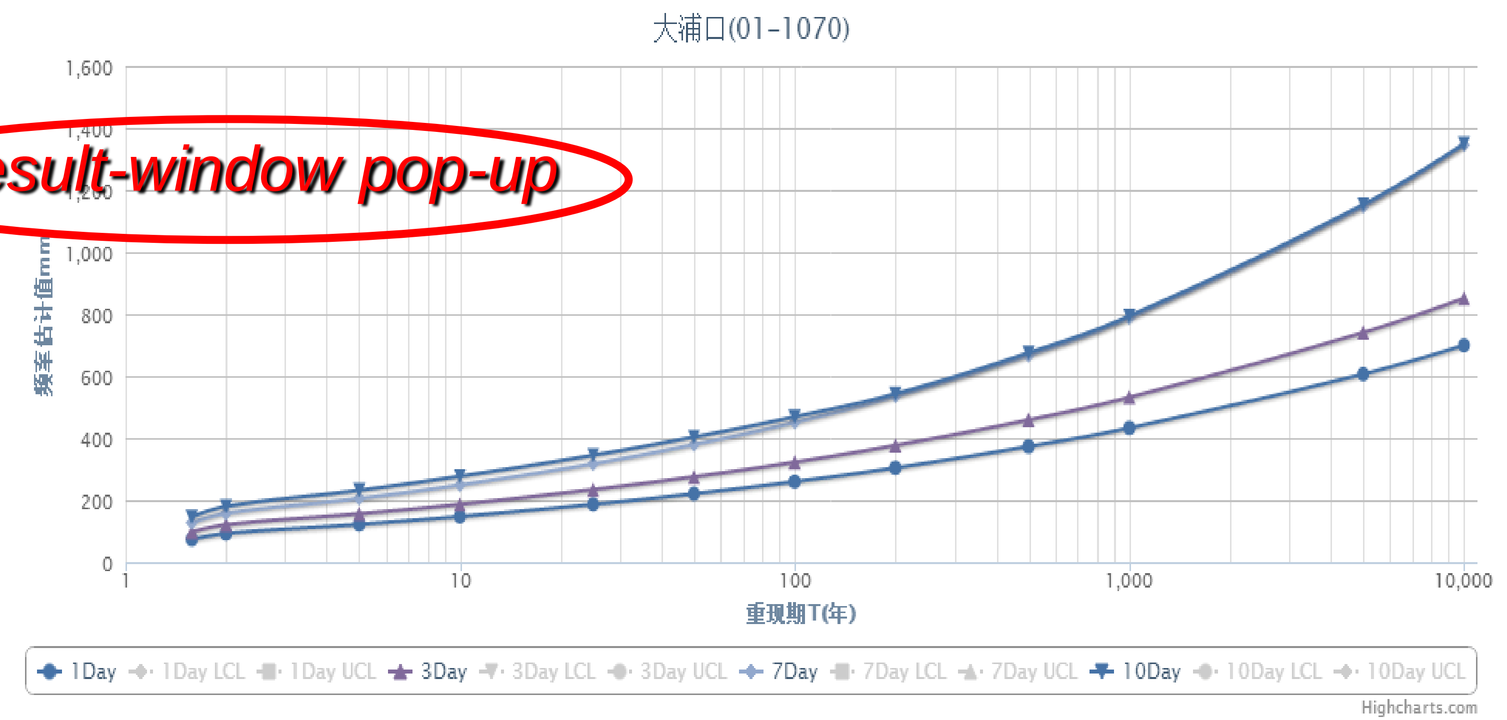
Online FA Deliverables (3)

大浦口(119.95,31.32)

Precipitation Frequency Estimates(mm)

ARI(Year)	Y1_58	Y2	Y5	Y10	Y25	Y50	Y100	Y200	Y500	Y1000	Y5000	Y10000
1 Day	73.57	92.46	121.48	146.97	186.19	220.61	259.47	304.18	372.78	433	606.75	[illegible]
3 Day	97.62	120.52	155.67	186.52	233.93	275.5	322.41	376.34	459	531.5	740.42	851.45
7 Day	126.77	157.18	205.22	248.57	317.11	378.91	450.37	534.5	667.2	786.88	1146.4	1345.07
10 Day	145.67	180.05	232.03	276.93	344.87	403.52	468.83	542.89	675.58	794.29	1153.6	1349.29

Example



A result-window pop-up

Fig. 24 Online FA products for Taihu Lake Basin (2)

Online FA Deliverables (4)

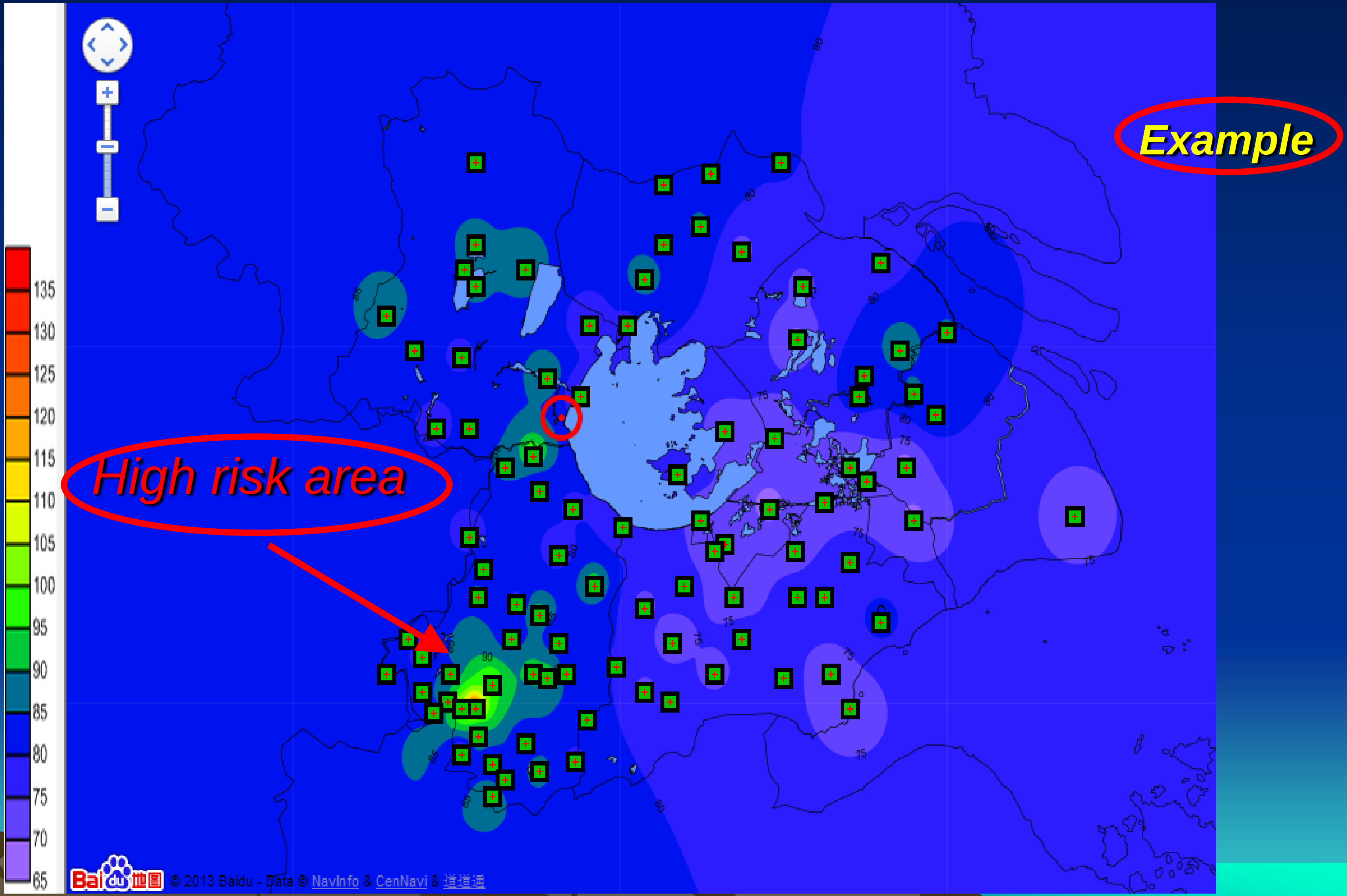


Fig. 25 Online FA products for Taihu Lake Basin (3)

江西省暴雨高风险区划 – 应用实例

- ***地形地貌***

- ***南高北低：由东、南、西三面向中部，由南向北逐渐倾斜于鄱阳湖***
- ***以山地和丘陵为主***
- ***山地多呈东北-西南走势***

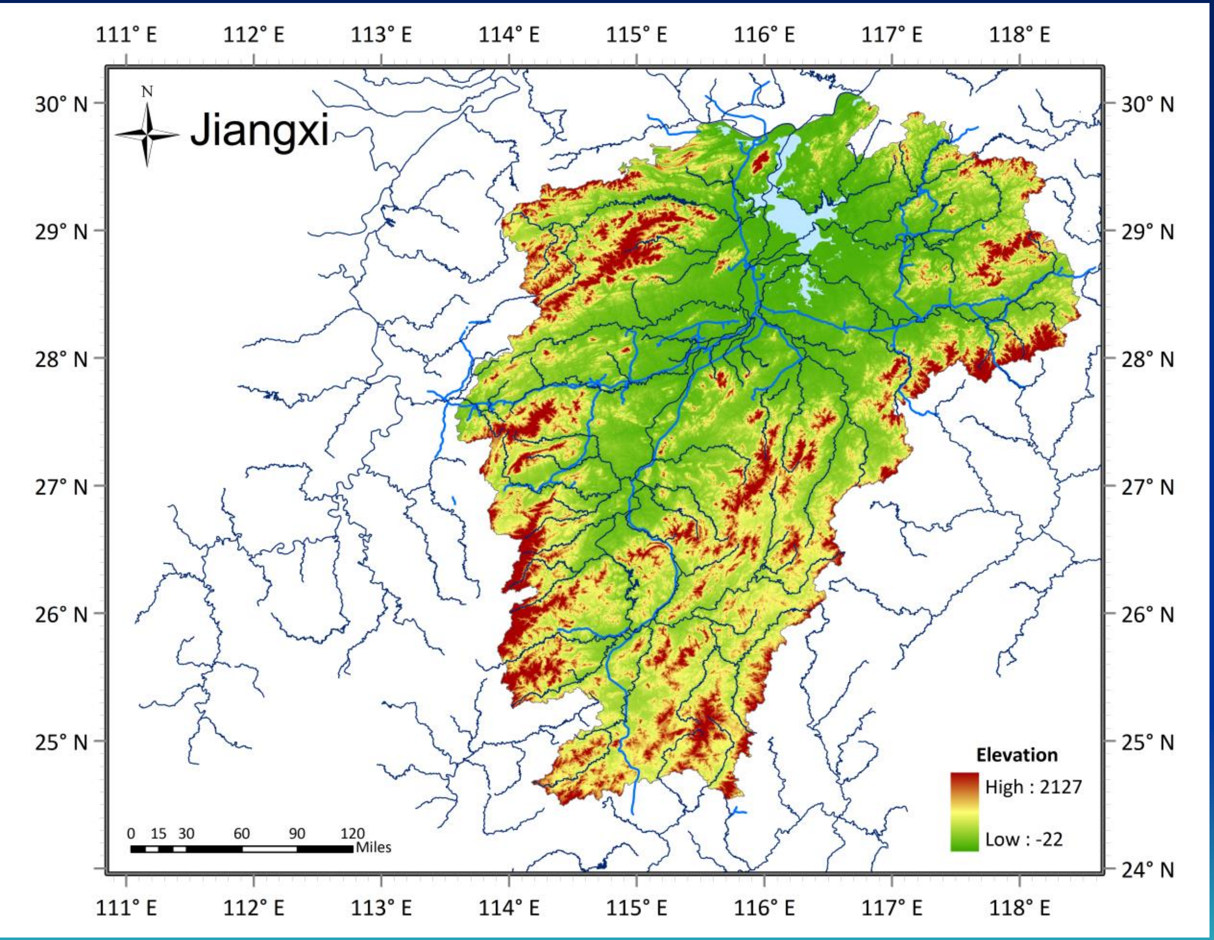


图2 江西省地形图

江西省雨量站点分布图

历时	有效站点数	有效观测长度	站点数
1h	1482	≥30year	374
		≥20year	544
		≥15year	688
3h	1491	≥30year	401
		≥20year	553
		≥15year	722
6h	1653	≥30year	515
		≥20year	742
		≥15year	959

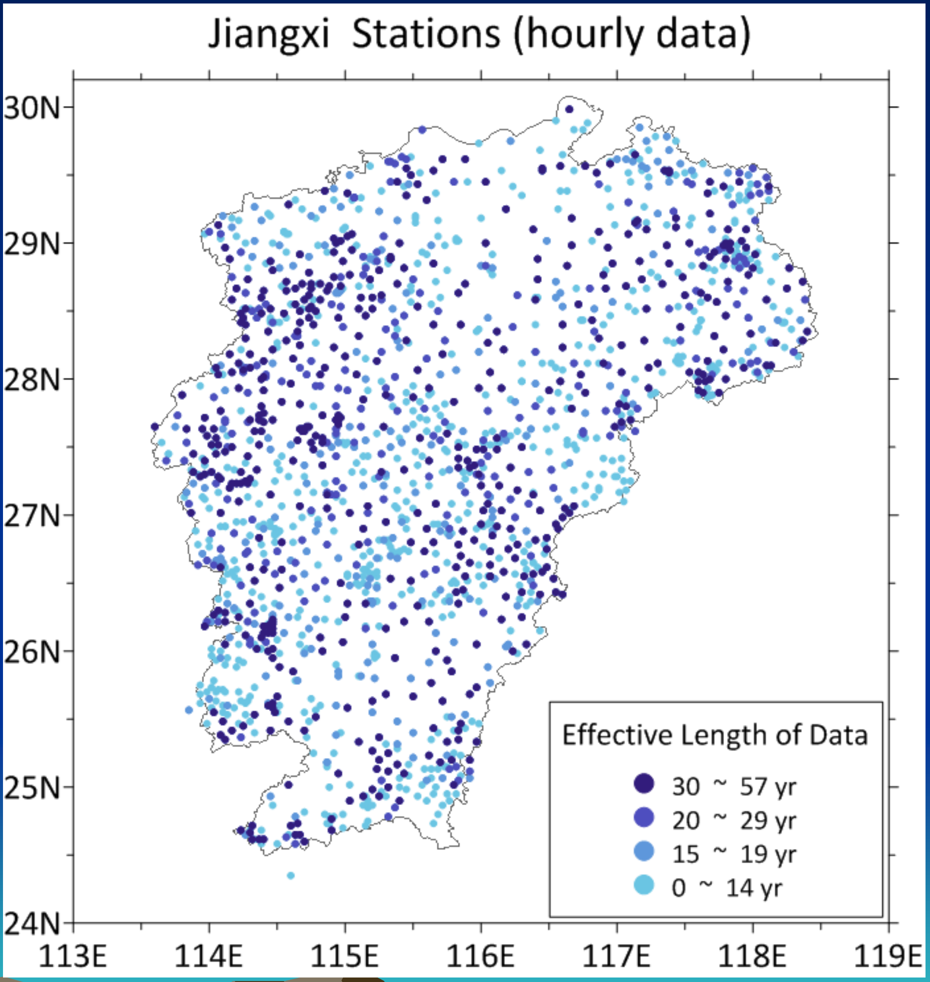
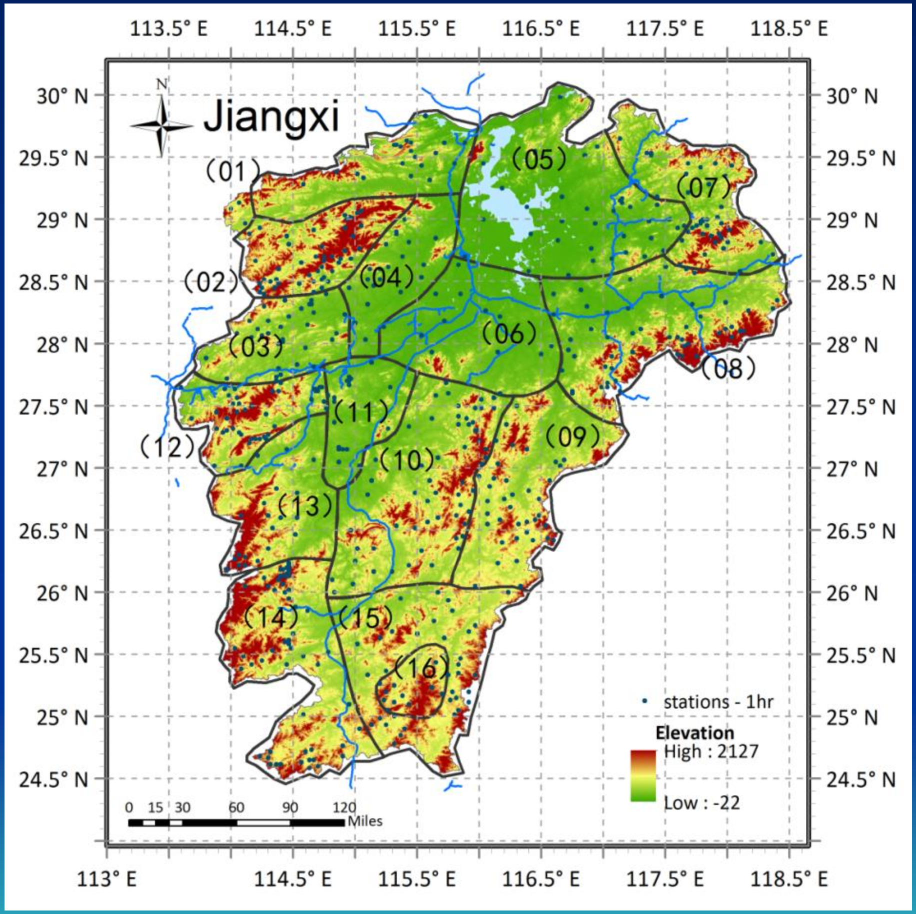


图3 江西省小时年最大值降雨资料有效站点（1653站）分布图

江西水文气象一致区的划分（1小时）



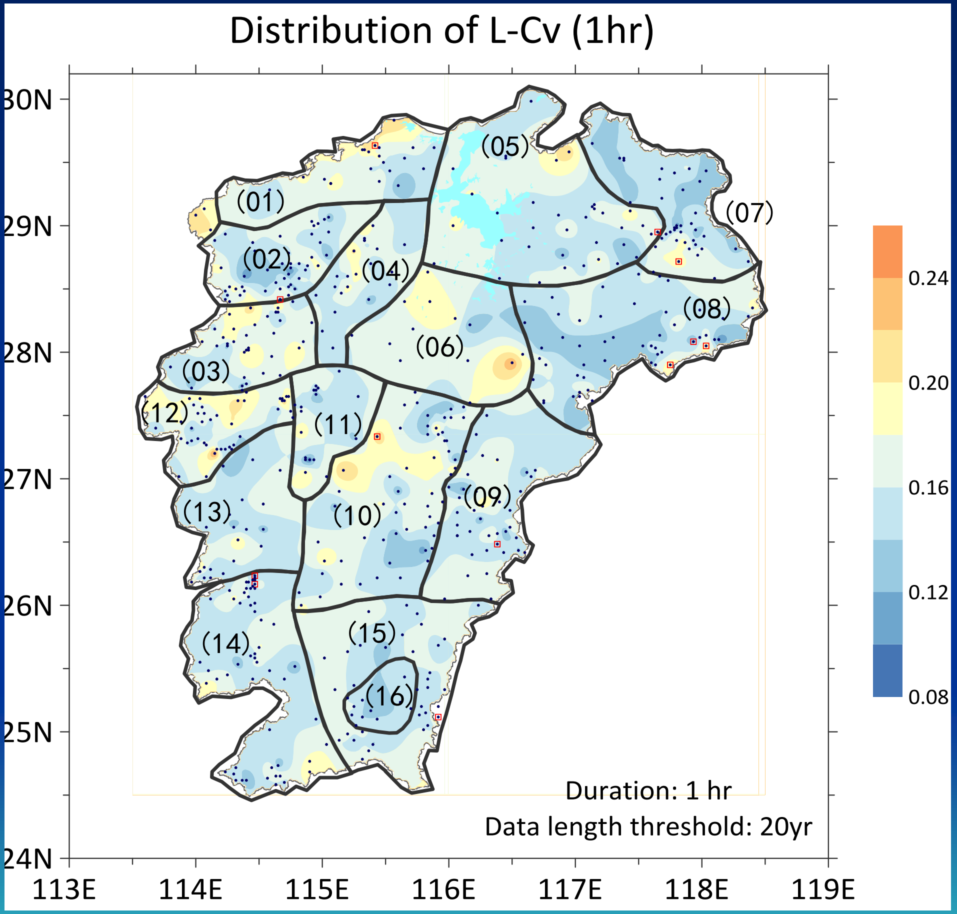
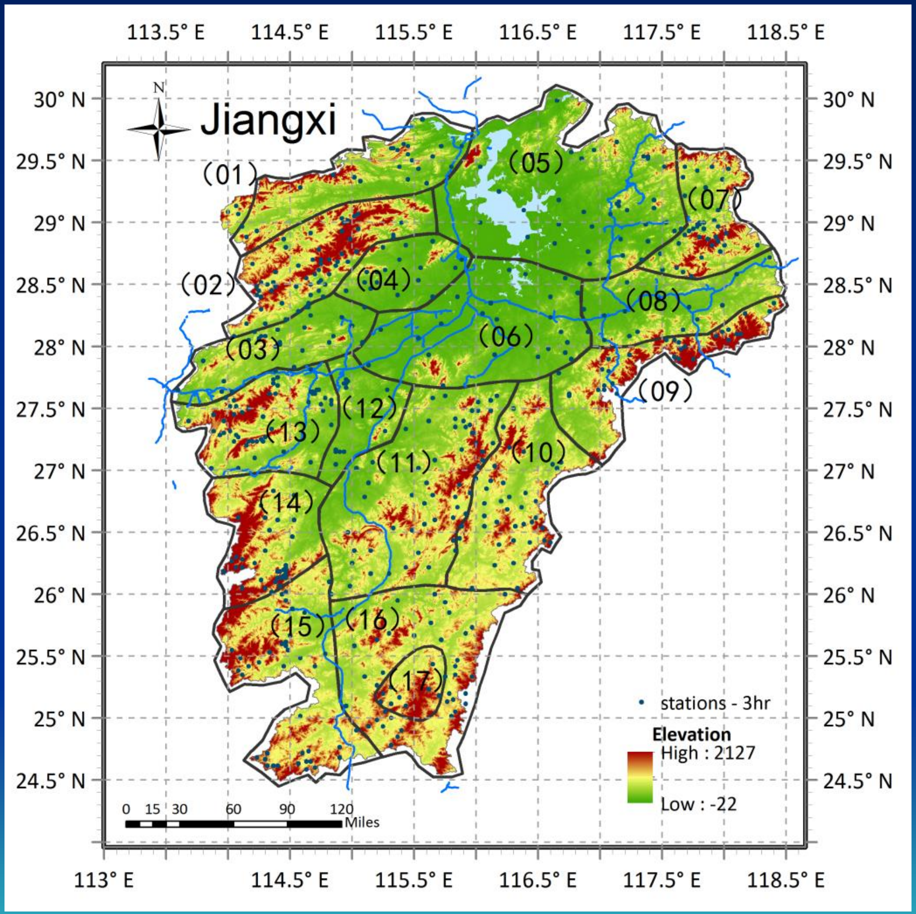


图4 江西省水文气象一致区划分示意图（1hr）

江西水文气象一致区的划分（3小时）



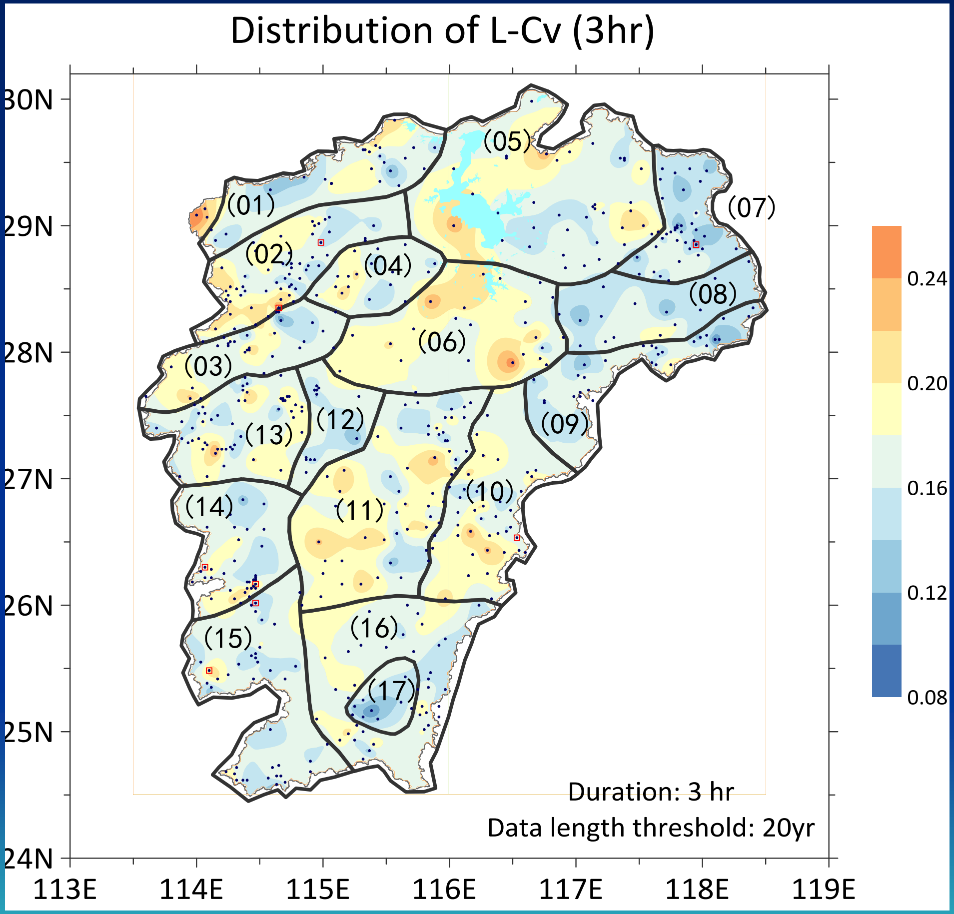
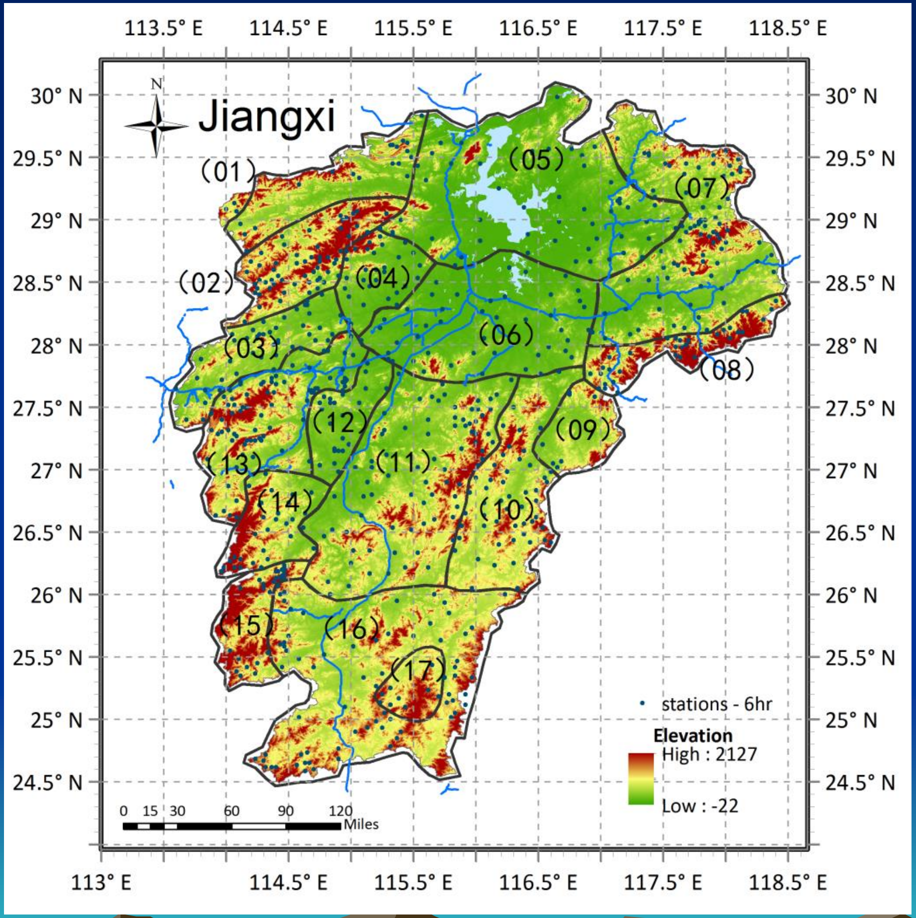


图5 江西省水文气象一致区划分示意图（3hr）

江西水文气象一致区的划分（6小时）



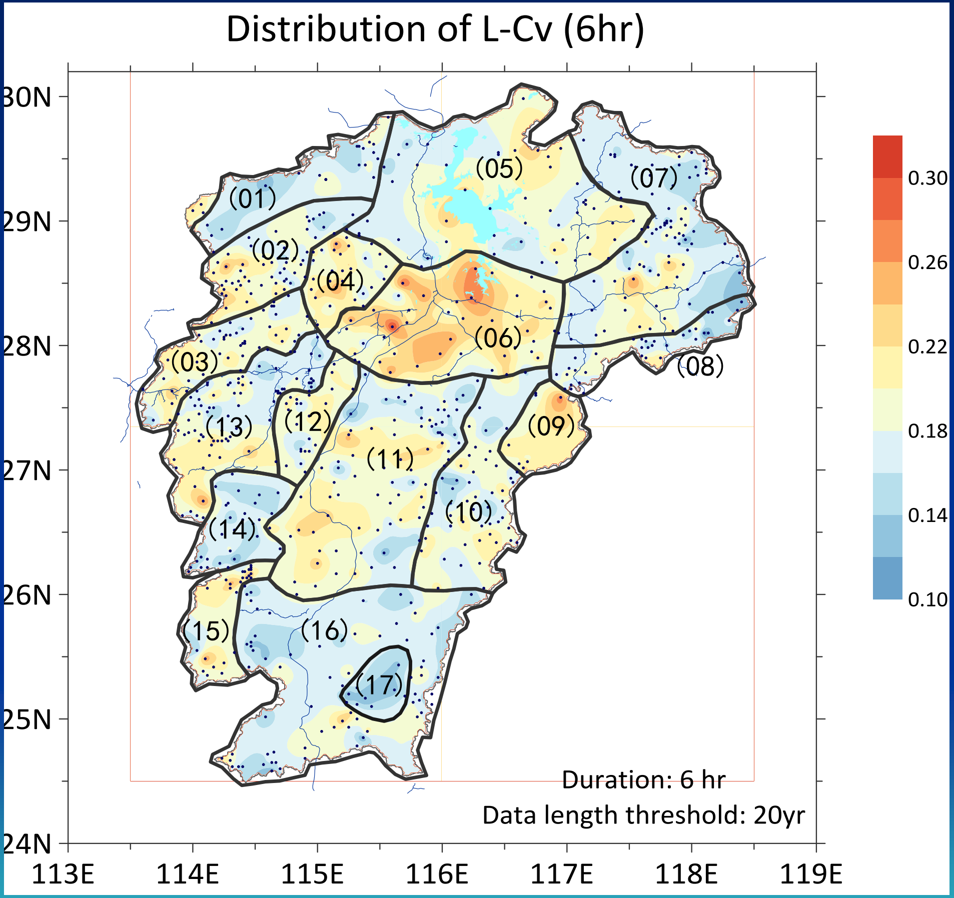


图6 江西省水文气象一致区划分示意图（6hr）

江西山洪暴雨高风险区划图（1-小时）

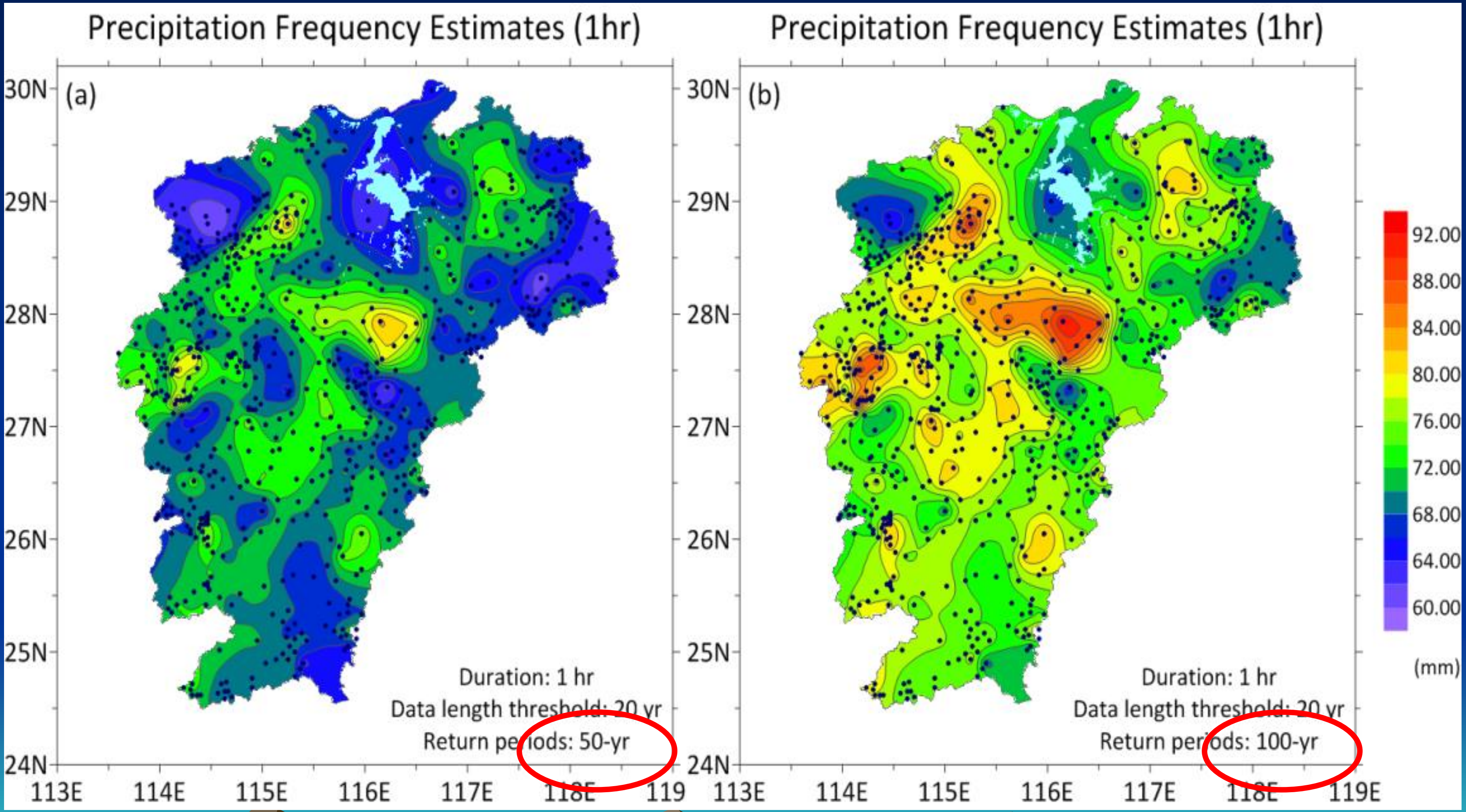


图13 江西省1hr 50年一遇(a)和100年一遇(b)暴雨高风险区划图

江西山洪暴雨高风险区划图（3-小时）

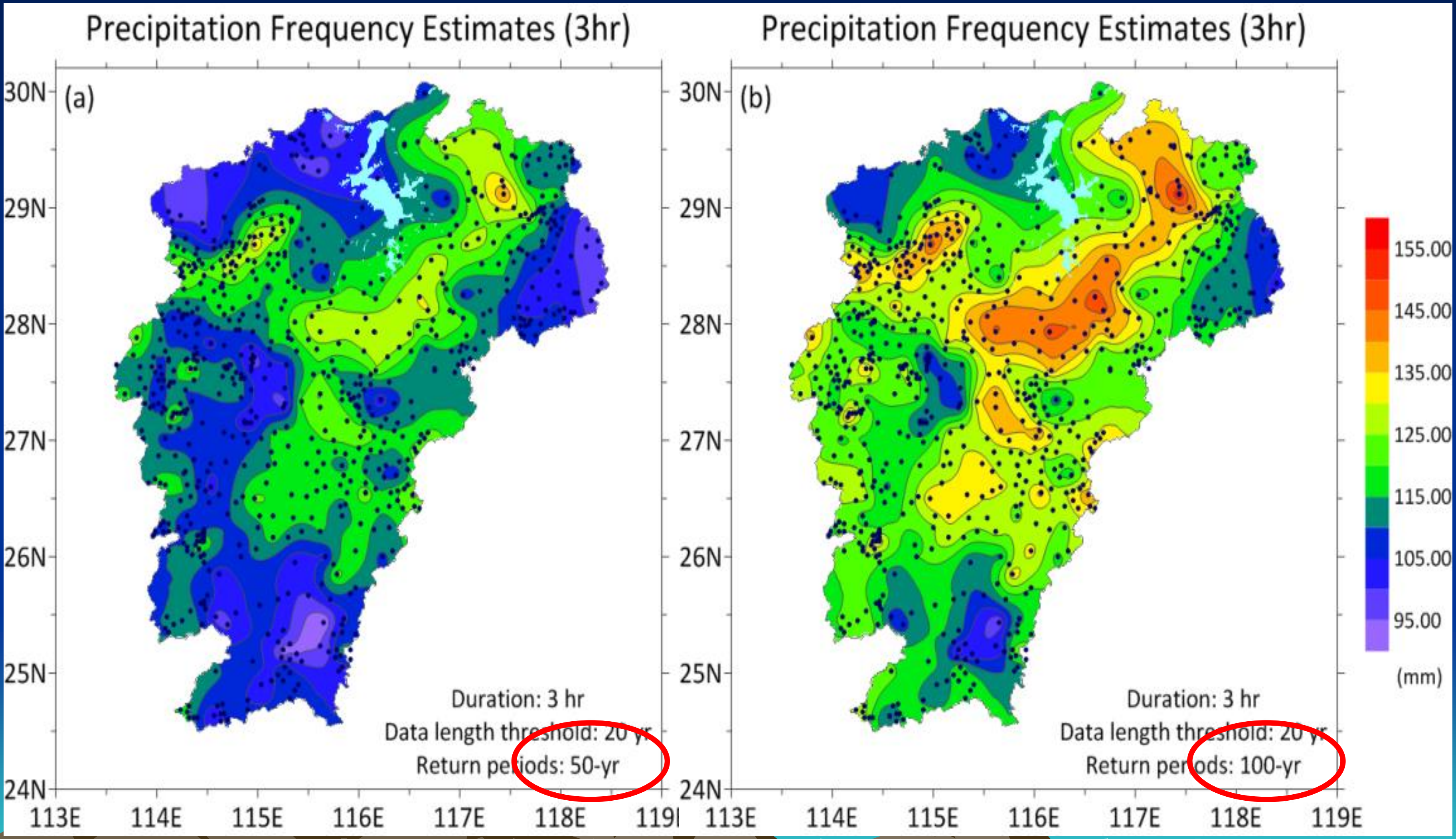


图14 江西省3hr 50年一遇(a)和100年一遇(b)暴雨高风险区划图

江西山洪暴雨高风险区划图（6-小时）

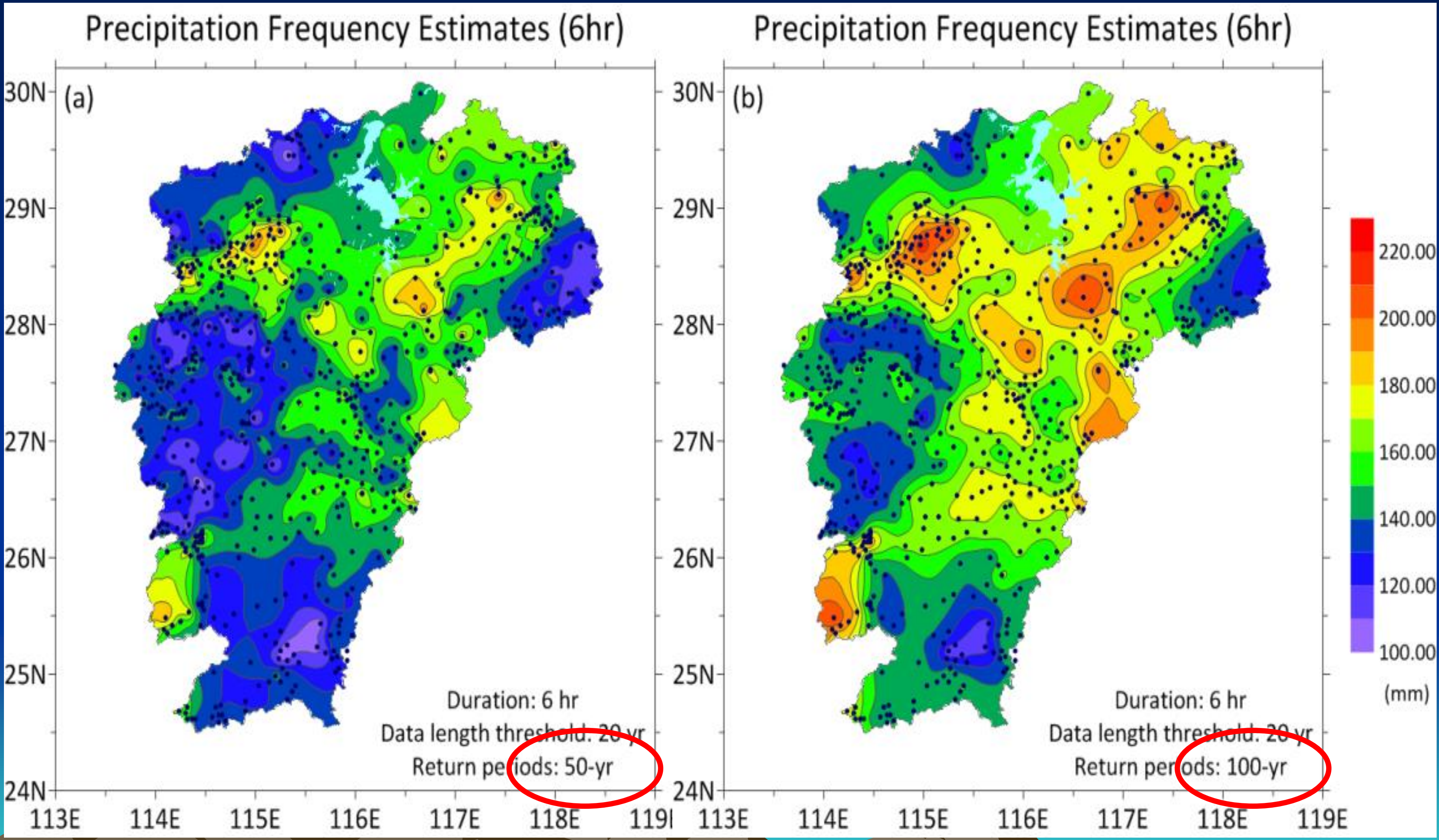


图15 江西省6hr 50年一遇(a)和100年一遇(b)暴雨高风险区划图

洪灾三大因素

1）强降雨；（山洪）

2）水土流失（山区）或下垫面过度硬化（城市）；（泥石流或城市洪涝）

3）行洪道上违规建设；（灾害）

水文气象学院研发“三张图”

“三张图”山洪预警预报系统：

1）静态的山洪暴雨高风险区划图（自然、科学基础图）

2）动态的临界河漫滩径流值图（缺水图）

3）动态的（卫星-雷达）临界雨量值图（来水图）

Another Mission

--Explore a meaningful upper limit of rainfall

In China Mainland PMP estimation is Required for design studies for large infrastructure（big dams、nuclear power stations）as regulatory standards in terms of flood-control, and flood-mitigation planning for large cities as well.

Probable Maximum Precipitation

-- Hydrometeorologically causal approach (成因分析）

Definition of PMP

Probable maximum precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed(1) or a given storm area(2) at a particular location ***at a particular time of Year***(3), with no allowance made for long-term climate trends.

(WMO No.-1045, *Manual on Estimation of PMP*, Geneva, 2009)

可能最大降水定义为*一年的特定时间中*(3)、在特定地点和给定时段内、在某一设计流域上(1)或者给定暴雨面积下(2)，气象上所可能降下的最大雨量；这个降水量没有考虑气侯的长期变化趋势。

（WMO “PMP估算手册”，第三版，2009年，日内瓦）

***Comments: (1) and (2) are not equivalent; (3) is irrelevant.**
--By Prof. B Lin

PMP Estimation Methodology -- International Practice

In general, mainly two types of approaches in design practice of PMP studies: I. Hydrometeorological (HYDROME) & II. Statistical (STAT)

(I-a) Moisture maximization	Maximum 12-hr persisting dew point (HYDROME)
(I-b) Storm transposition	Storm Separation + Adjustments (HYDROME)
(I-c) Use of D-A-D curves	Envelopment (HYDROME)
(II) Statistical approach	Modified frequency analysis (STAT)

The most popular means – *Storm Transposition* (ST)

The most difficult job is how to take ST in terrain area – orographic effects?

Key： **Storm separation**

- **Convergence component**
- **Orographic component**

Synoptic +Statistics+ Orographic

For a storm rainfall, the rainfall intensity for a given point P(x,y) in a drainage at any time can be defined by

$$I(x,y,t)=I_0(x,y,t)\times f(x,y,t)$$

（Lin，1988；WMO No-1045，2009）

（SDOIF method*）

Hence, the area-averaged rainfall R for the whole drainage area of A during the period of time is given below:

$$\overline{R}_{\Delta t,A}=\frac{\iint_A r_{\Delta t}(x,y)dxdy}{\iint_A dxdy}=\frac{\iint_A r_{0,\Delta t}(x,y)\times f_{\Delta t}(x,y)dxdy}{\iint_A dxdy}\approx\frac{\sum_i^m\sum_j^n r_{0,\Delta t}(x_i,y_j)\times f_{\Delta t}(x_i,y_j)dxdy}{\sum_i^m\sum_j^n \Delta x_i\Delta y_j}$$

（* Lin，Bingzhang， WMO NO-1045，Geneva，2009）

12 Tasks for the PMP Study in HK

Example

- Inception report
- Historical rainfall data acquisition (SE China)
- Storm survey/selection and analysis
- Transposition analysis of selected storms
- Synoptic analysis + apply the storm separation
- technique (SDOIFs)
- Statistical estimation
- Orientation + transposition adjustment
- Development of DAD with moisture maximization
- Impact of climate change/Long-term trends in rainfall extremes
- Comprehensive comparisons
- Final report

Procedures

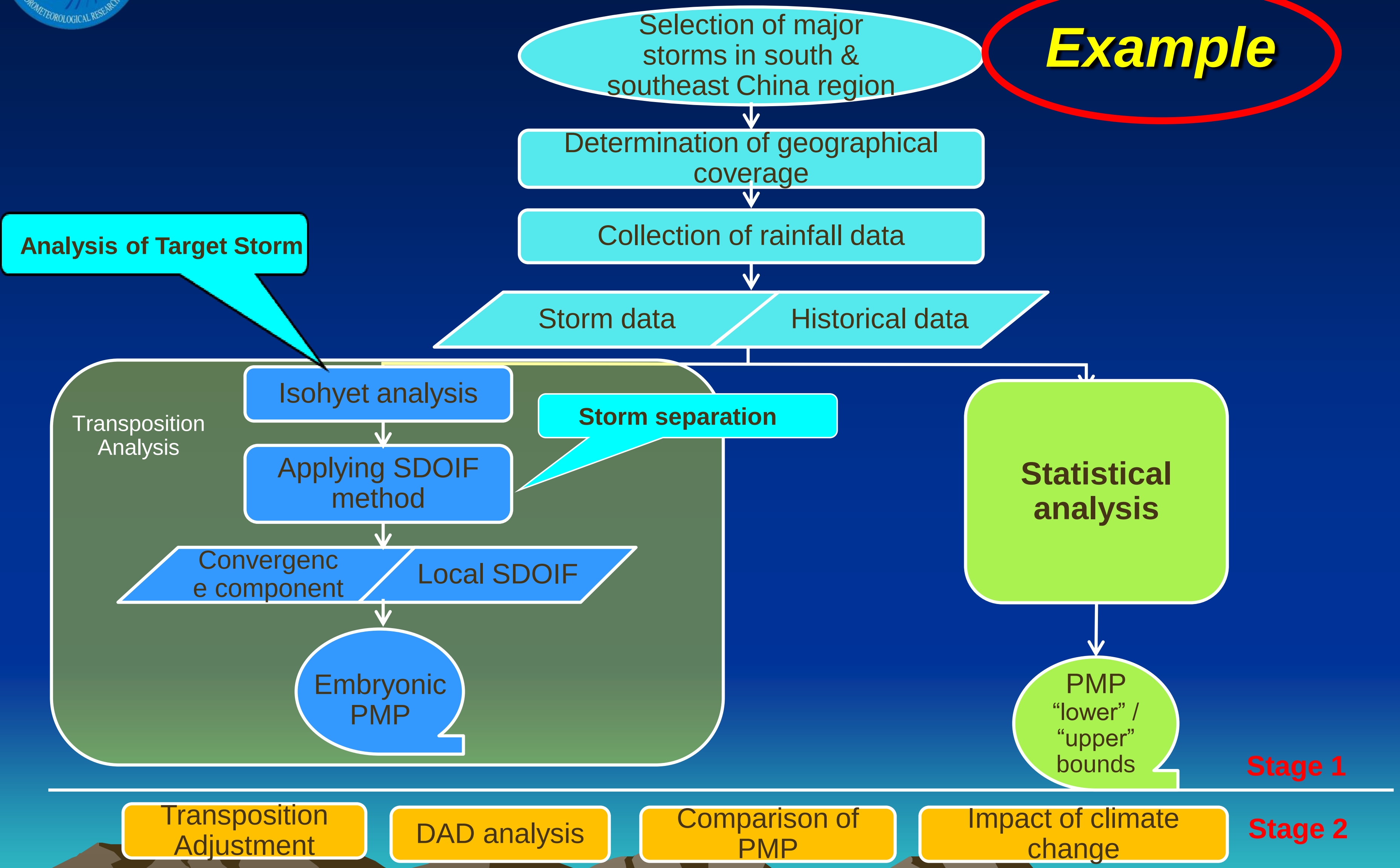


Fig. 29 Sketch of PMP estimation procedure for HK as example

Moving track of Morakot Typhoon

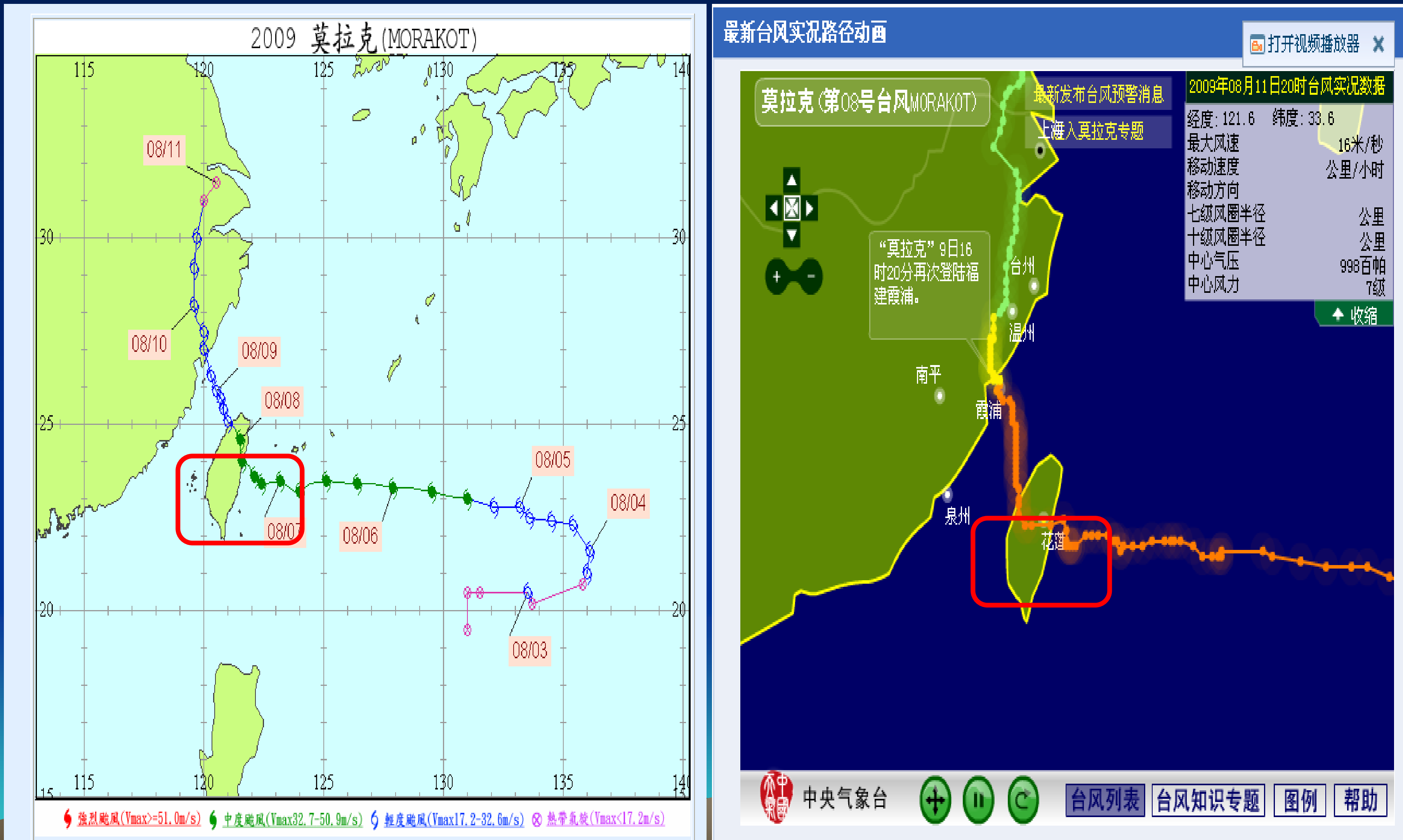


Fig. 30 Track of Morakot Typhoon, 2009-08-03~11

World, China mainland and Taiwan rainfall records (By 2009)

Shinliao, Taiwan (north)	October 17, 1967	24-hour	**1,672 mm**	**Taiwan record**
Jiayi Zhongpu, Taiwan	**August 8, 2009**	**24-hour**	**1,583** mm	Typhoon Morakot
Linzhuang, China mainland	August 7, 1975	24-hour	1,060 mm	Sup. Typhoon Nina
Cilaos， La Reunion Island	March 15, 1952	24-hour	**1,870 mm**	Tropical Cyclone
Pindong Weiliaosan, Taiwan	**August 8-9, 2009**	**48-hour**	**2,327 mm**	**Typhoon Morakot**
Linzhuang, China mainland	August 7-8, 1975	48-hour	1,279 mm	Sup. Typhoon Nina
Cilaos， La Reunion Island	March 15-17, 1952	2-day	**2,500 mm**	Tropical Cyclone
Jiayi Alisan, Taiwan	**August 8-10, 2009**	**3-day**	**2,777 mm**	**Typhoon Morakot**
Linzhuang, China mainland	August 6-8, 1975	3-day	1,605 mm	Sup. Typhoon Nina
Cilaos， La Reunion Island	March 15-18, 1952	3-day	3,240 mm	Tropical Cyclone
Grand-llet, La Reunion Island	January 24-27, 1980	3-day	3,241 mm	Cyclone Hyacinthe
Commerson's Crater，La Reunion Island	February 24-26, 2007	3-day	**3,929 mm**	**Cyclone Gamede**

Issue of the Typhoon Morakot (1)

(1,000-year plus event?)

Lessons/findings learnt from the Morakot:

Total rainfall >> historical records in the Mainland China

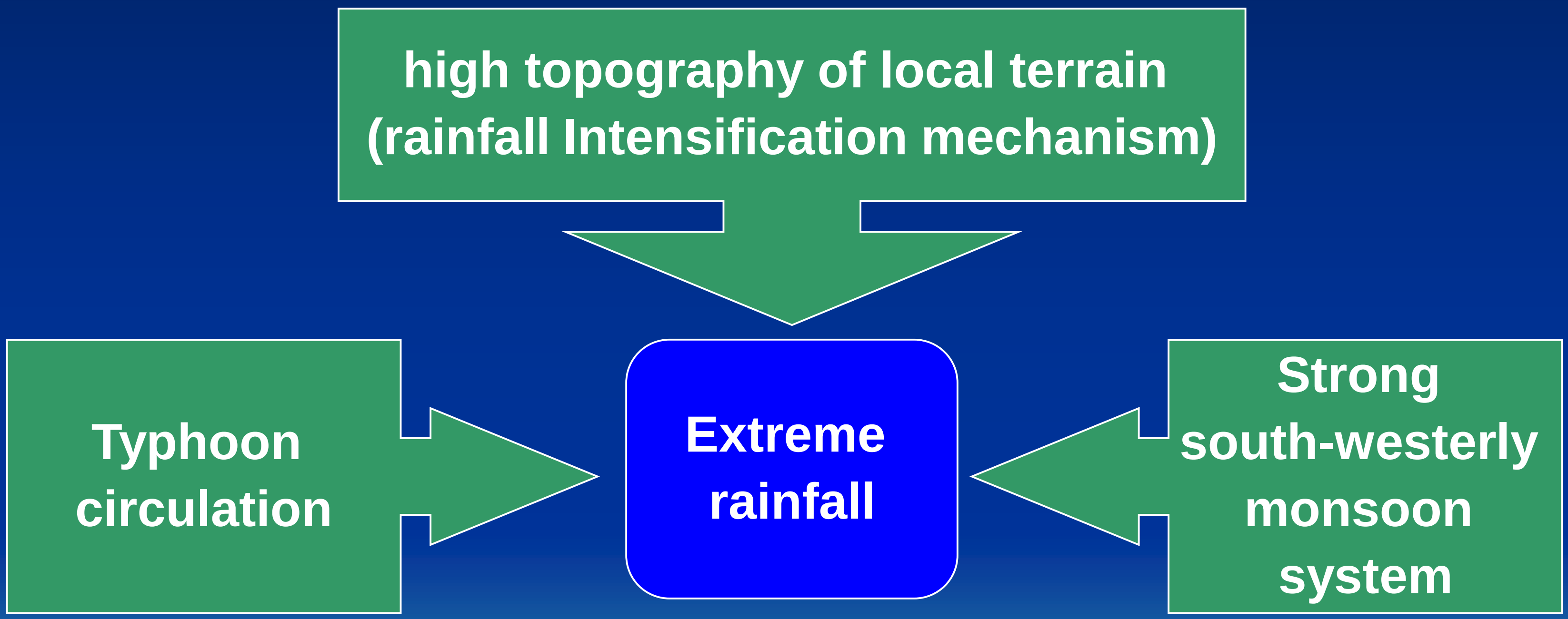
24-hr rainfall >> 1,000-year estimate in U.S. and PRVI

24-hr rainfall ~ 24-hr PMP estimate on Hainan Island

2-day rainfall ~ the world record

Issue of the Typhoon Morakot (2)

Possible causes:



However, current typhoon intensity forecast skill is still poor because of the lack of understanding on the complex interactions between ocean and typhoons

Fig. 31 Sketch of causes for Morakot Typhoon Storm

Isohyets of 24-hr for Morakot Typhoon

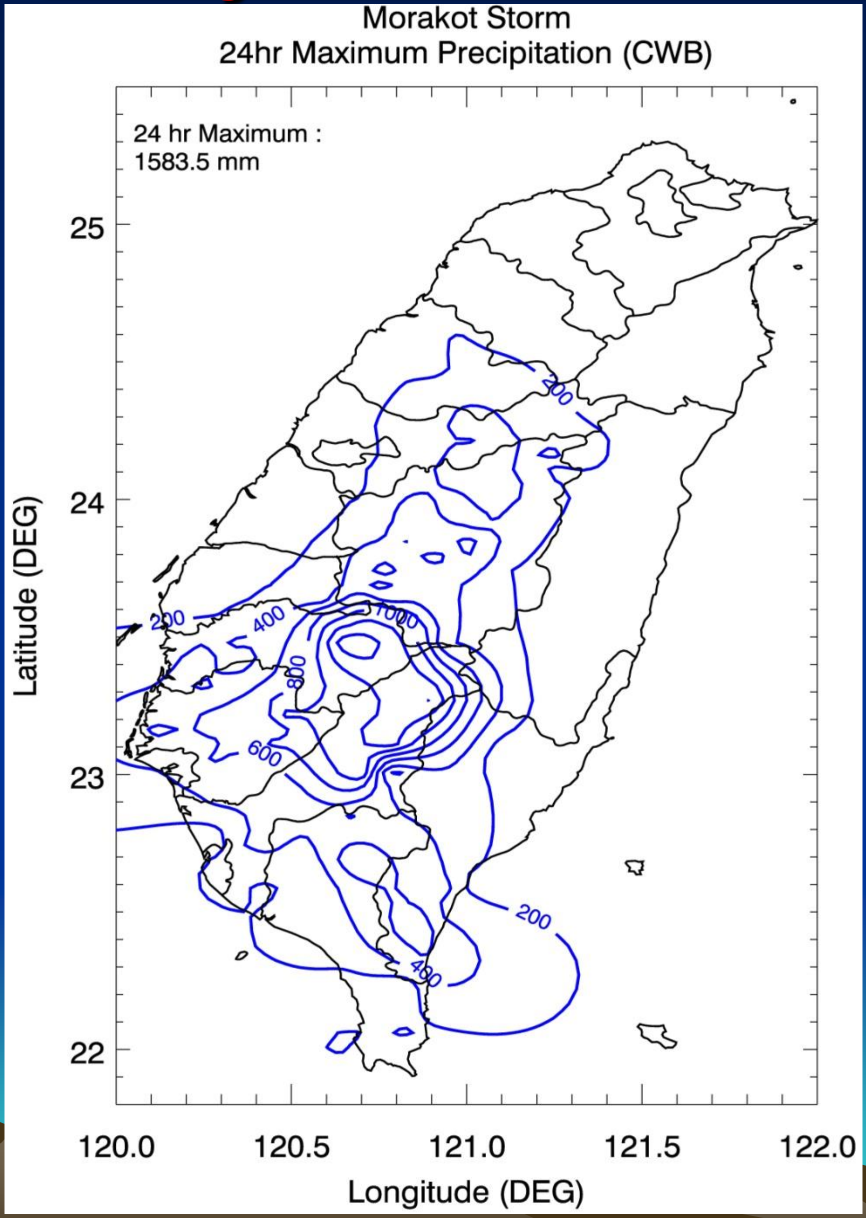


Fig. 32 24-hr isohyets of Morakot Storm

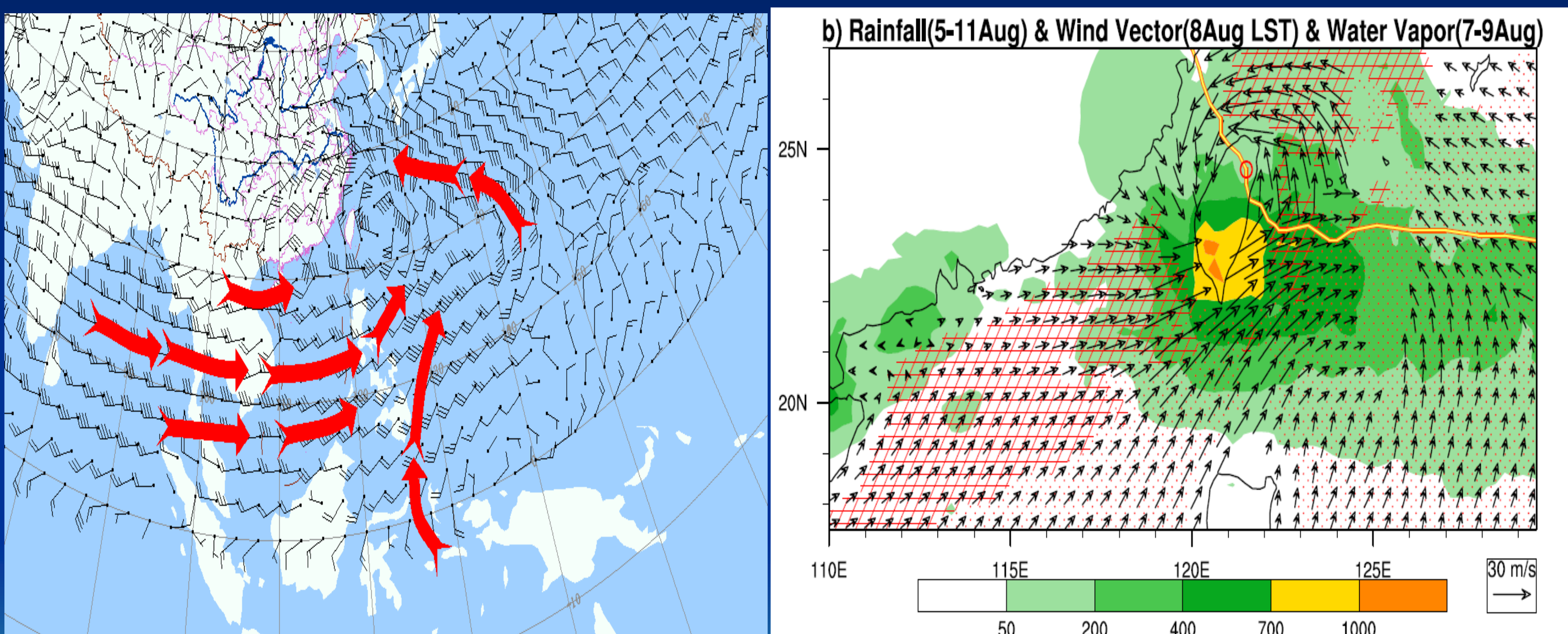
- **1,583mm / 24-hr**
- **2,372mm / 48-hr**
- **2,682mm / 72-hr**

(based on hourly rainfall observations)

Moisture Flux of Morakot Storm

Development of the SDOIF for the Target Area

- Major Moisture Flux during Morakot (left)

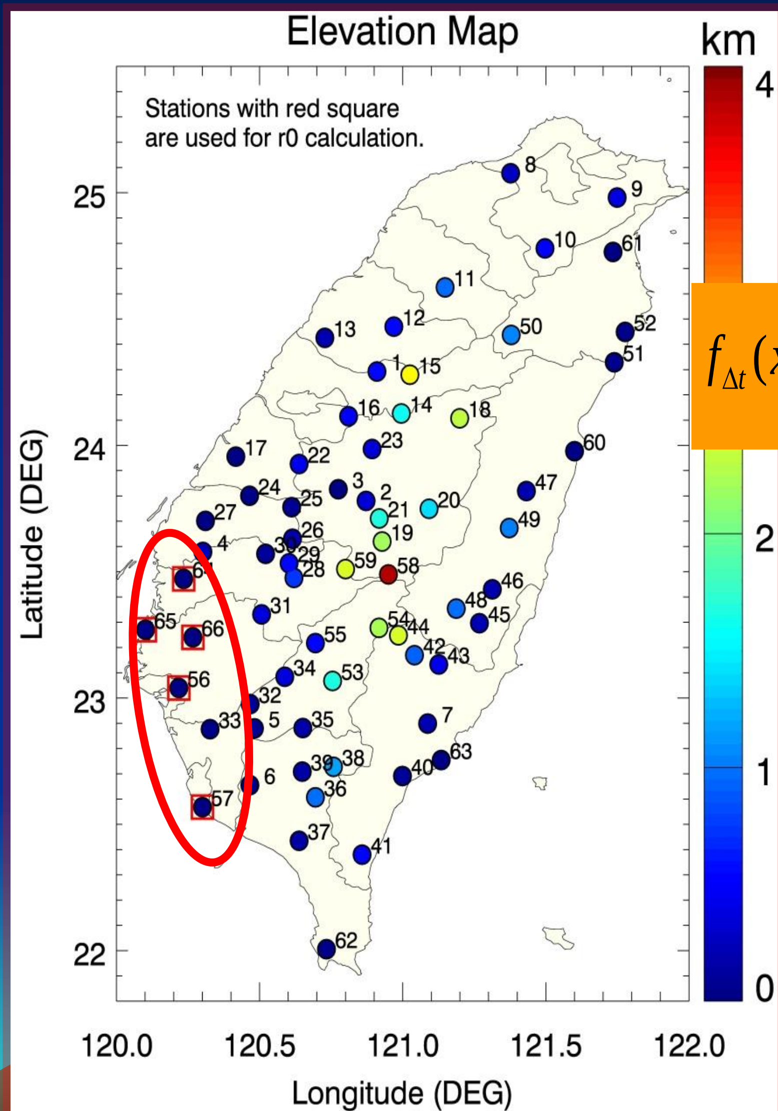


- Power Spectrum of the WNPSM Index (right)
- *(After Chi–Cherng Hong, Taipei Municipal University of Education, Taipei, Taiwan)*

Fig. 33 Model simulation of moisture flux for Morakot Typhoon

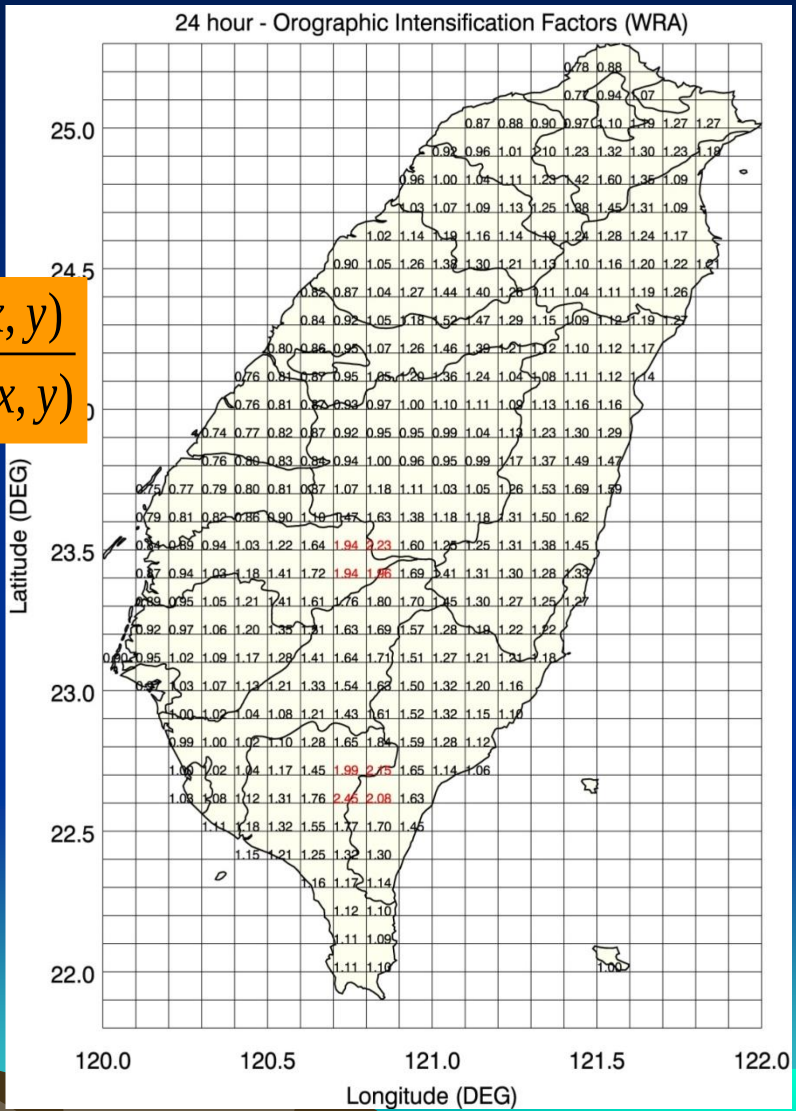
Basic Raingauges & SDOIF

（分时段地形增强因子法）

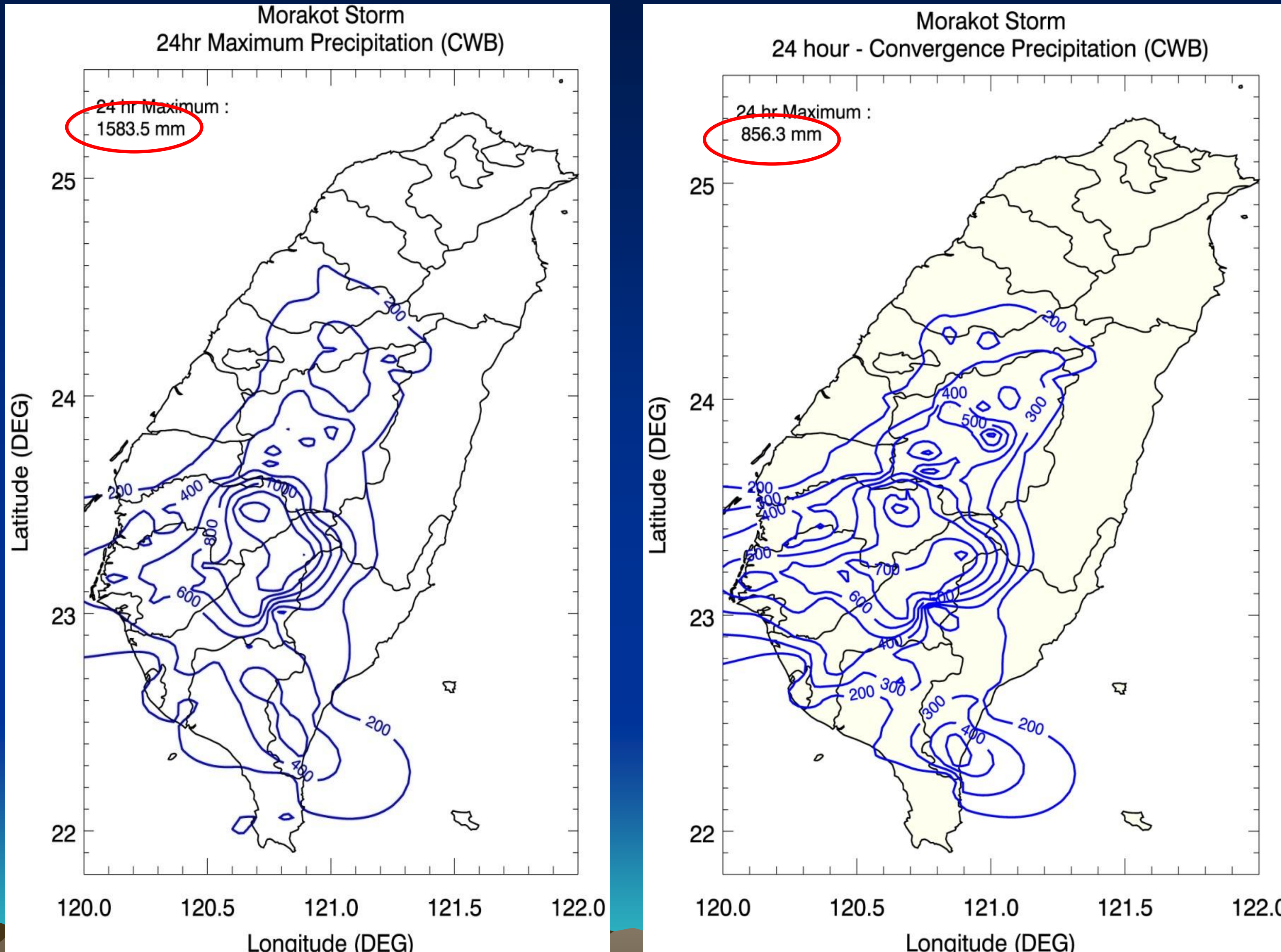


$$f_{\Delta t}(x,y) = \frac{r_{\Delta t}(x,y)}{r_{0,\Delta t}(x,y)}$$

eqn. (1) →

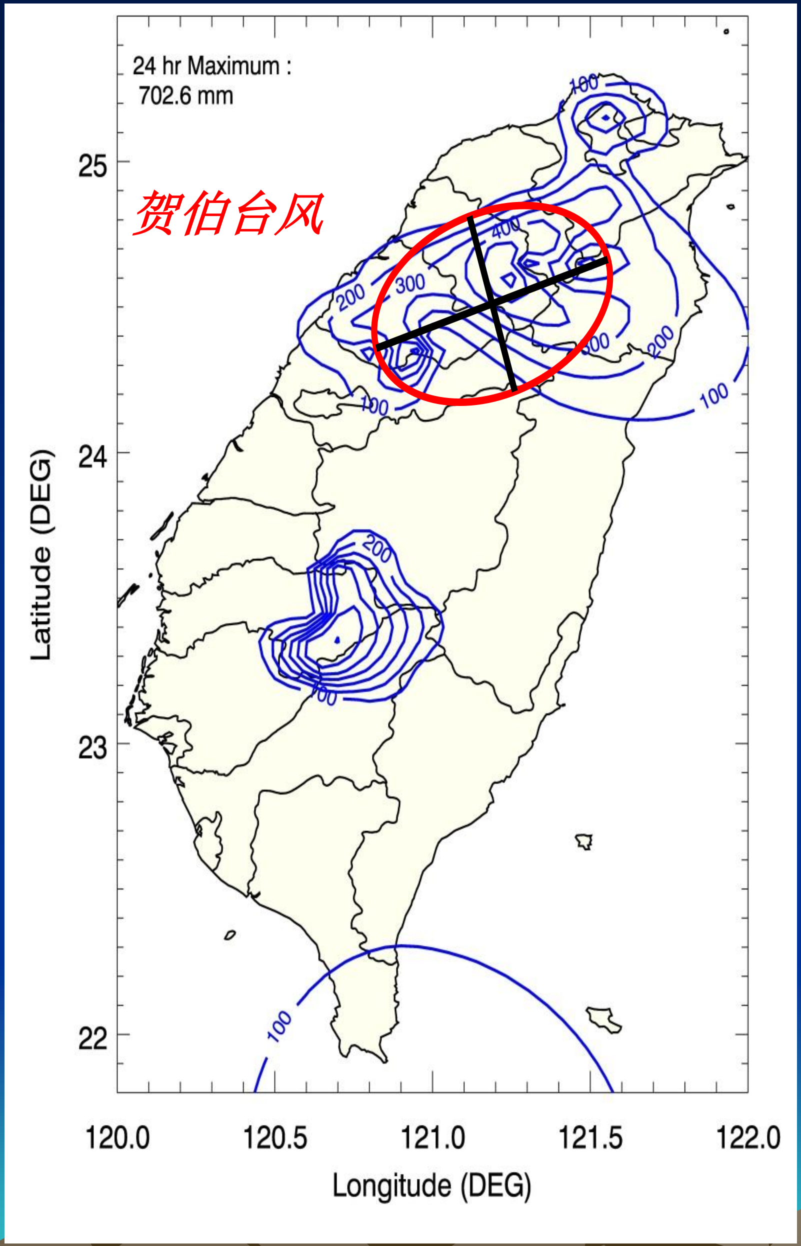


Before & After Storm Separation

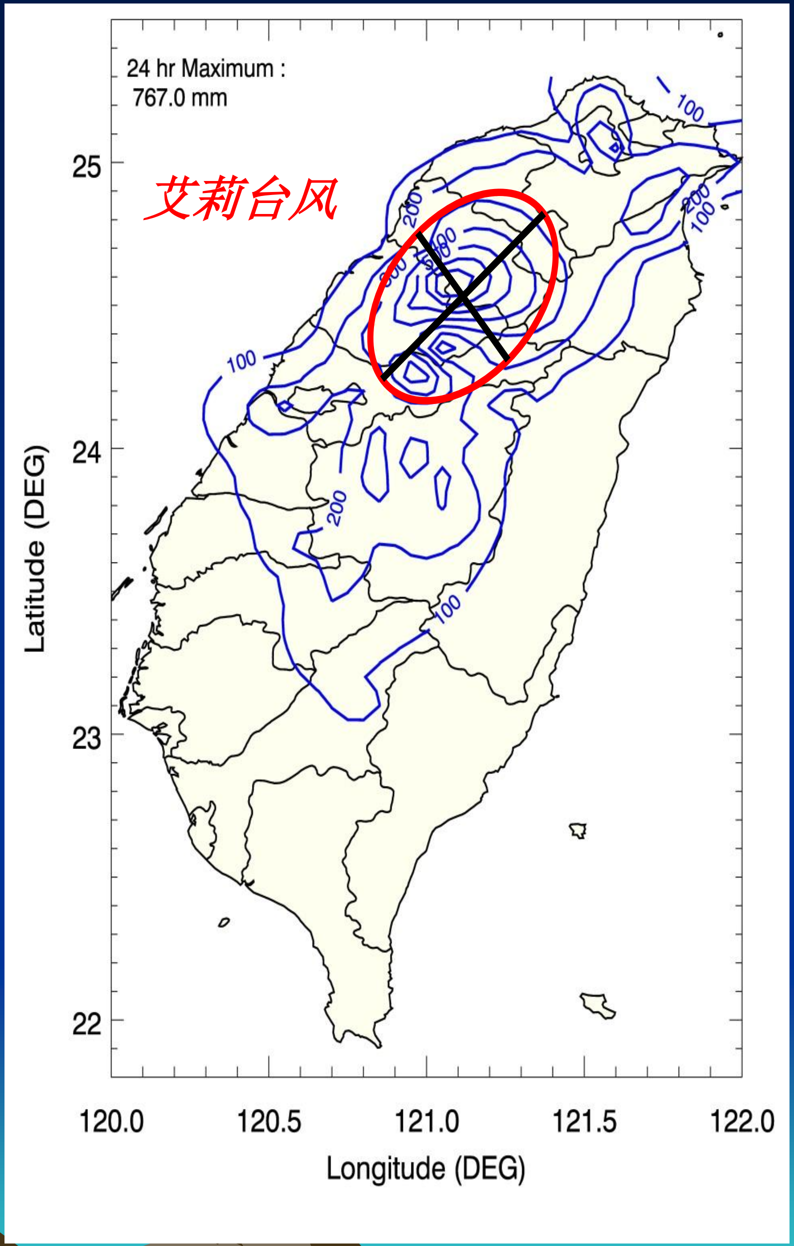


Before After

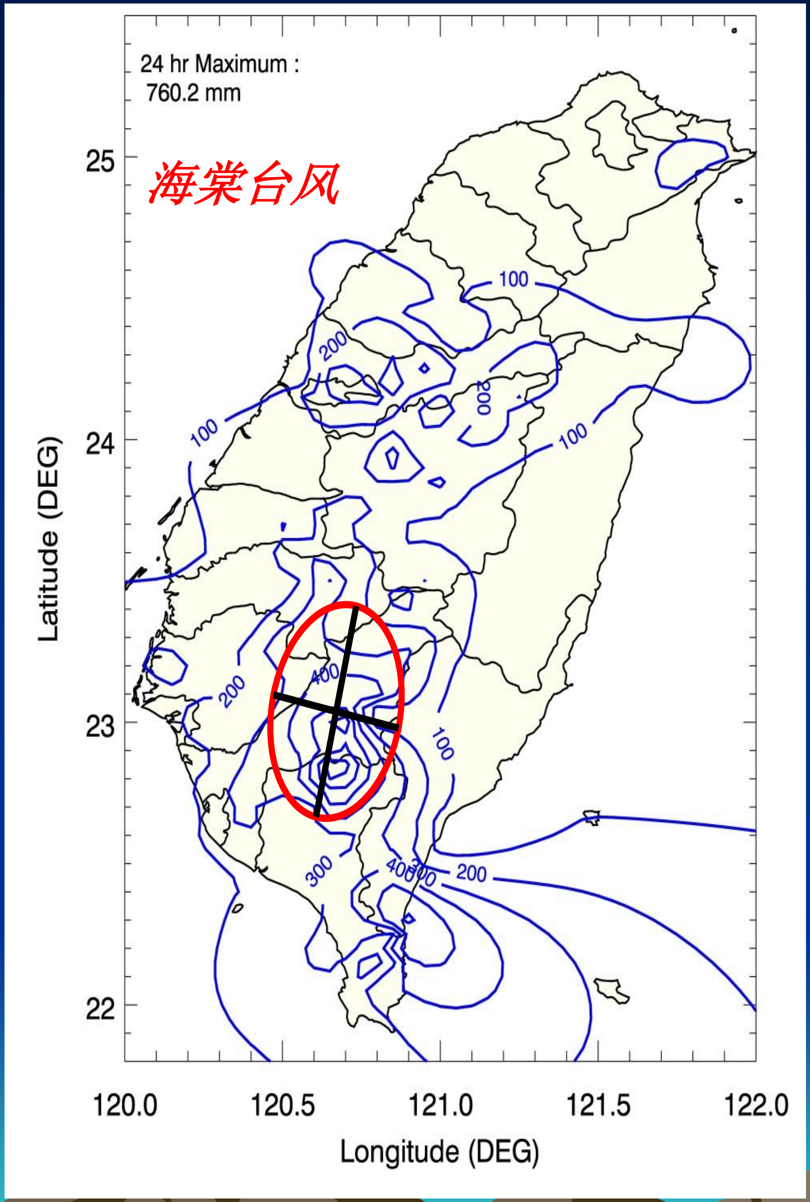
Fig. 36 Before and after decomposition of 24-hr Morakot Storm



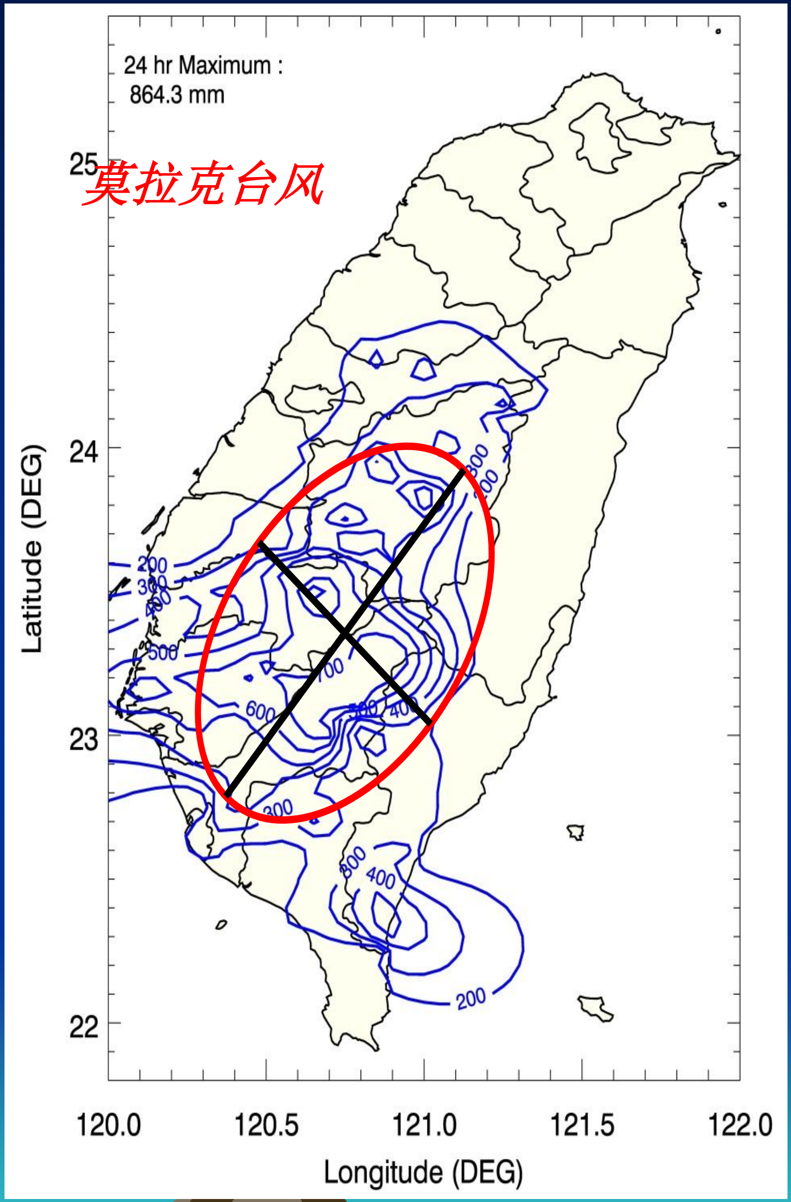
The Shape of the Generalized Convergence Component Pattern of Storm Herb of 1996.7.31~8.2



The Shape of the Generalized Convergence Component Pattern of Storm Aere of 2004.8.24~26



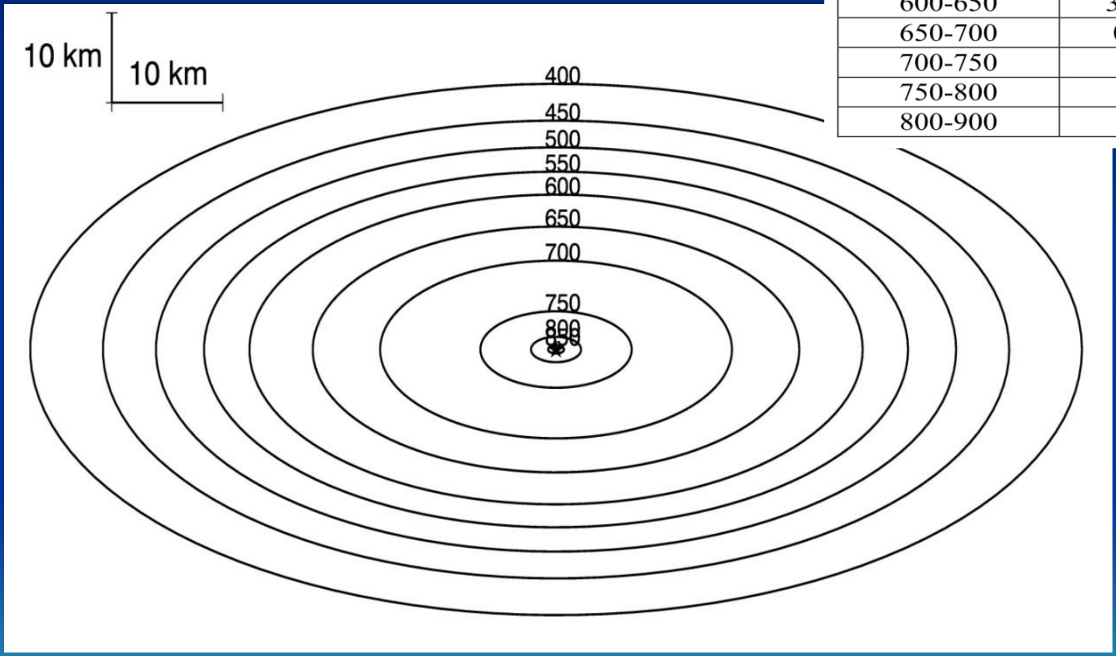
The Shape of the Generalized Convergence Component Pattern of Storm Haitang of 2005.7.18~20



The Shape of the Generalized Convergence Component Pattern of Storm Morakot of 2009.8.8~10

Generalized Convergence Component Pattern

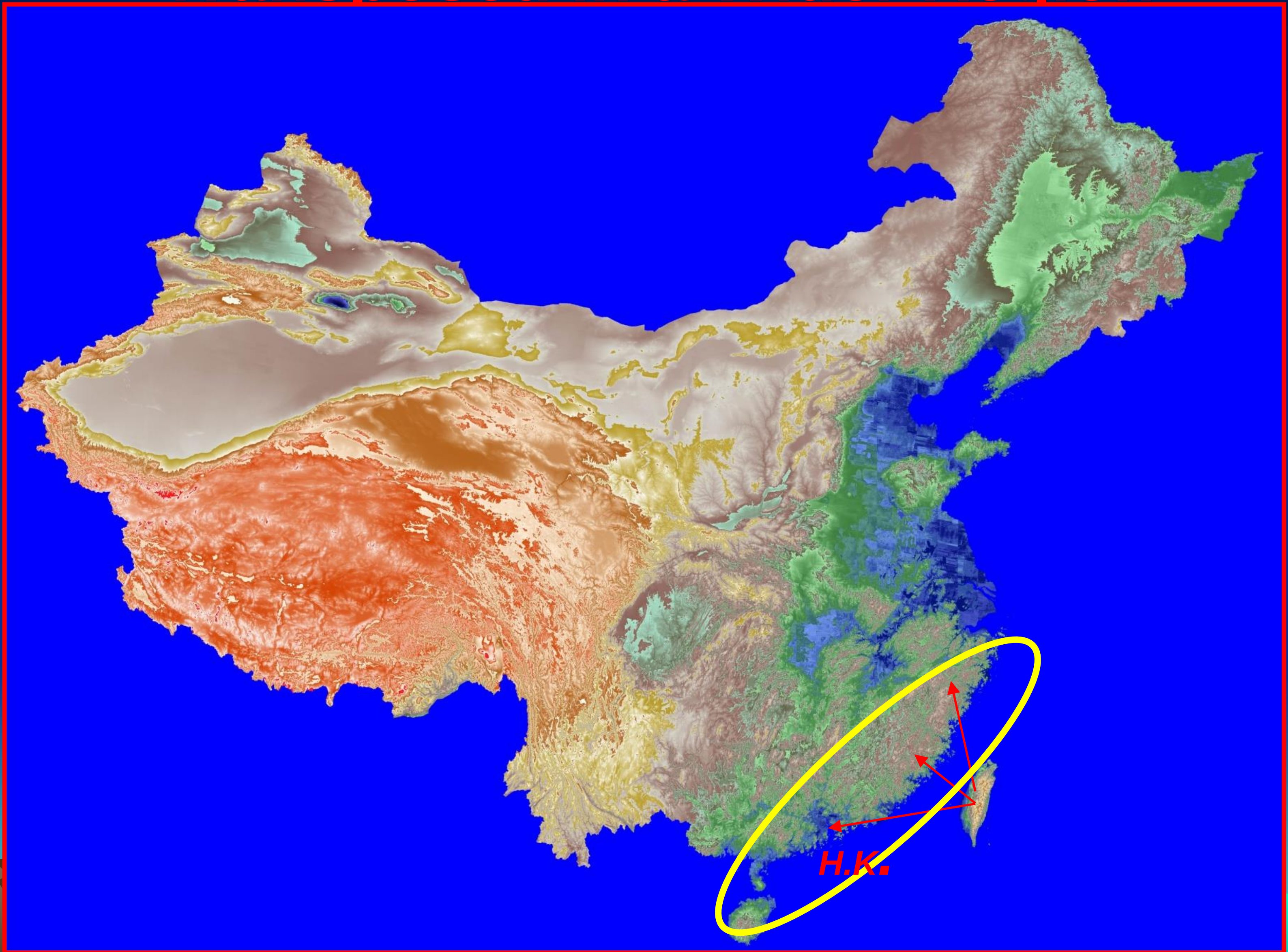
Isohyets (mm)	Area (km^2)				
	Herb	Aere	Haitang	Morakot	Generalised Convergence Component Patter
0-50	26206	28181	13220	14690	14690
50-100	6075	3157	6436	5757	5757
100-150	4053	2257	4647	5061	5061
150-200	1266	2418	6134	5371	5371
200-250	1149	2116	4230	2128	2128
250-300	946	1478	2510	1677	1677
300-350	613	759	1853	1230	1230
350-400	395	340	1036	1131	1131
400-450	289	225	590	1133	1133
450-500	236	166	385	720	720
500-550	113	124	286	576	576
550-600	68	72	82	476	476
600-650	39	55	40	554	554
650-700	0	45		449	449
700-750		33		401	401
750-800		22		81	81
800-900				10	10



Convergence component pattern of storm

Average ratio: r = major radius / minor radius = 1.6 （based on the shape of 300mm isohyets over the four major storms）

Convergence Pattern can be Transposed in a Wider Region



Application example: Transposed to HK

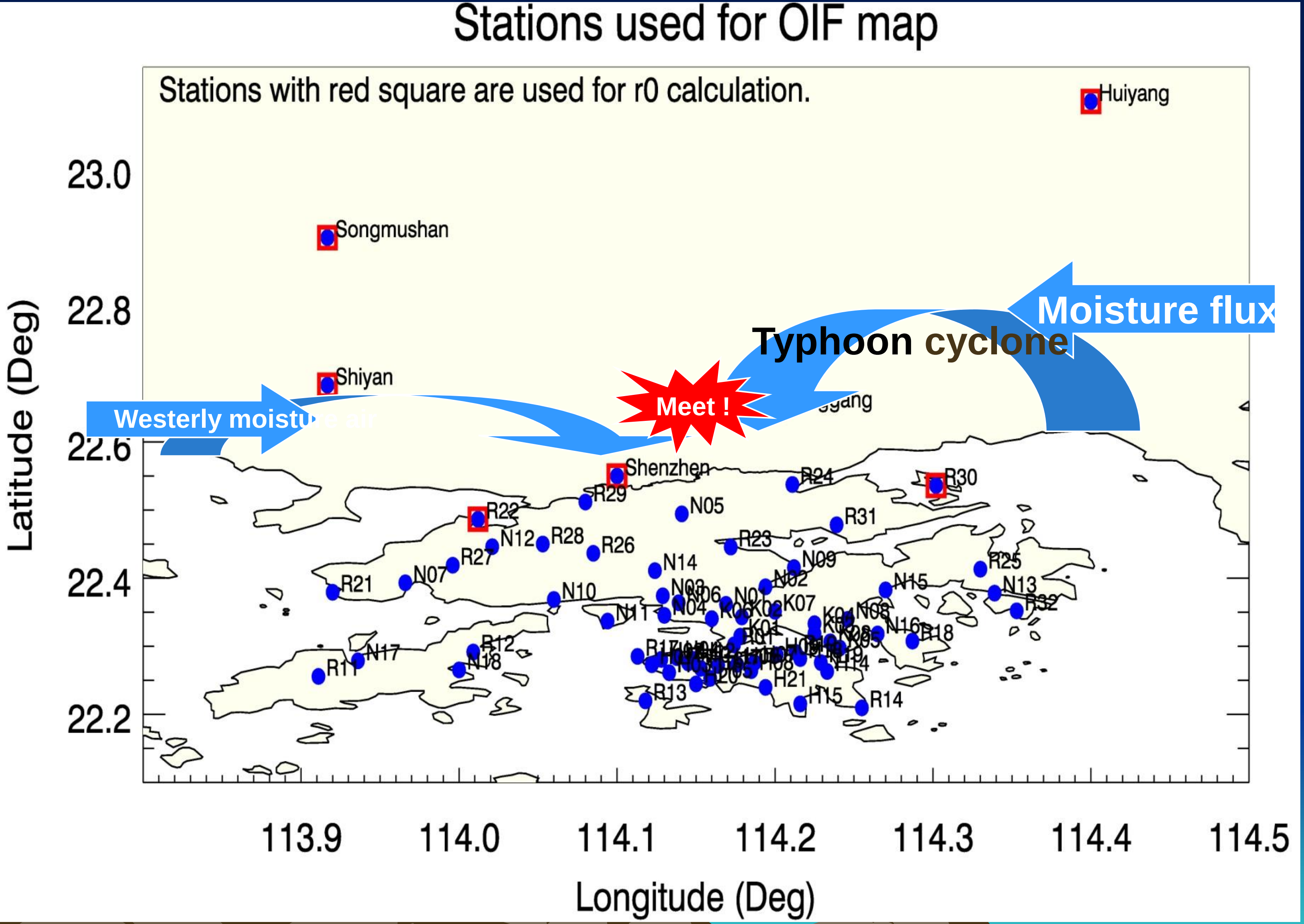
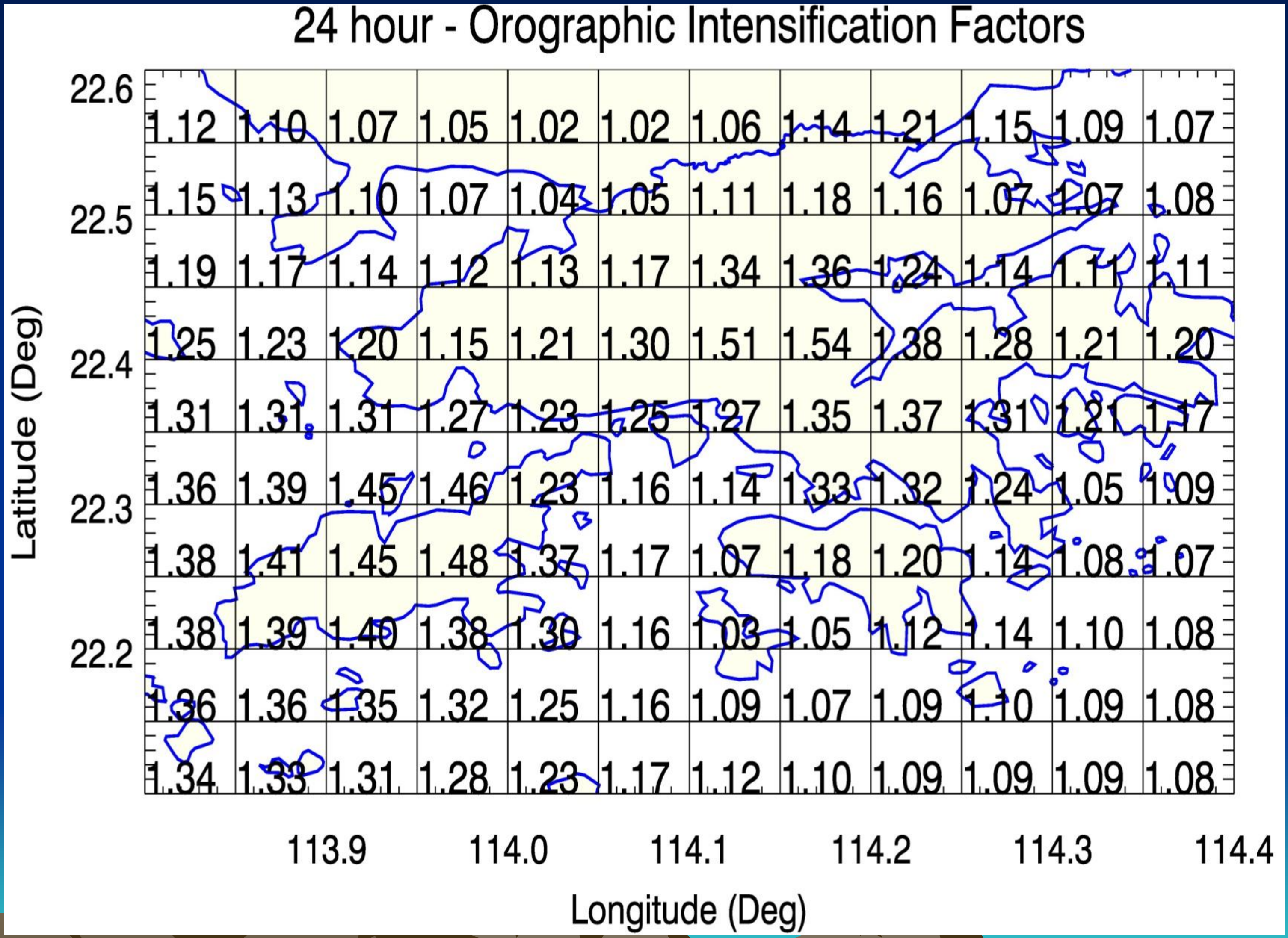


Fig. 39 Illustration of synoptic analysis for HK in terms of moisture flux

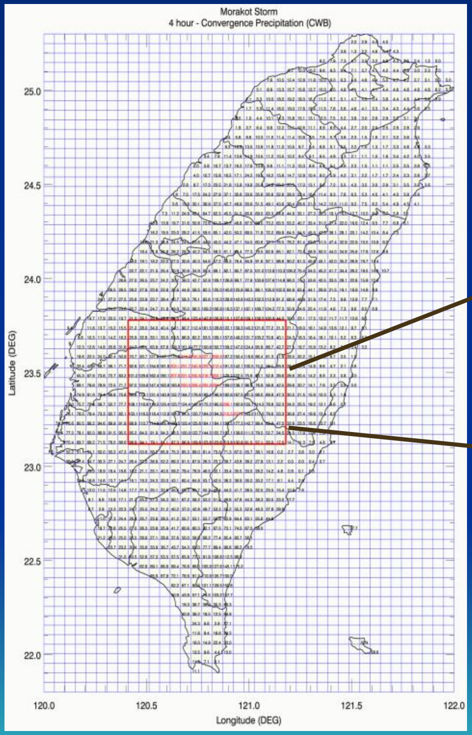
Development of OIF in Design Area, HK

(5kmx5km)

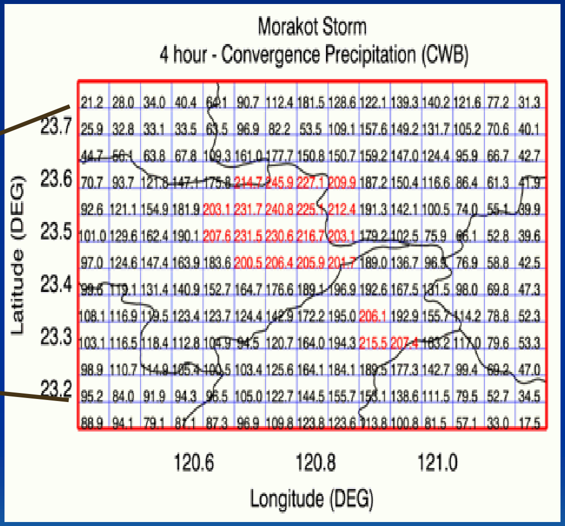


Convert the Convergence into gridded

- Convert the convergence component of Morakot into a gridded frame like the gridded SDOIF
- Then cut-off the center piece to match the HK area size



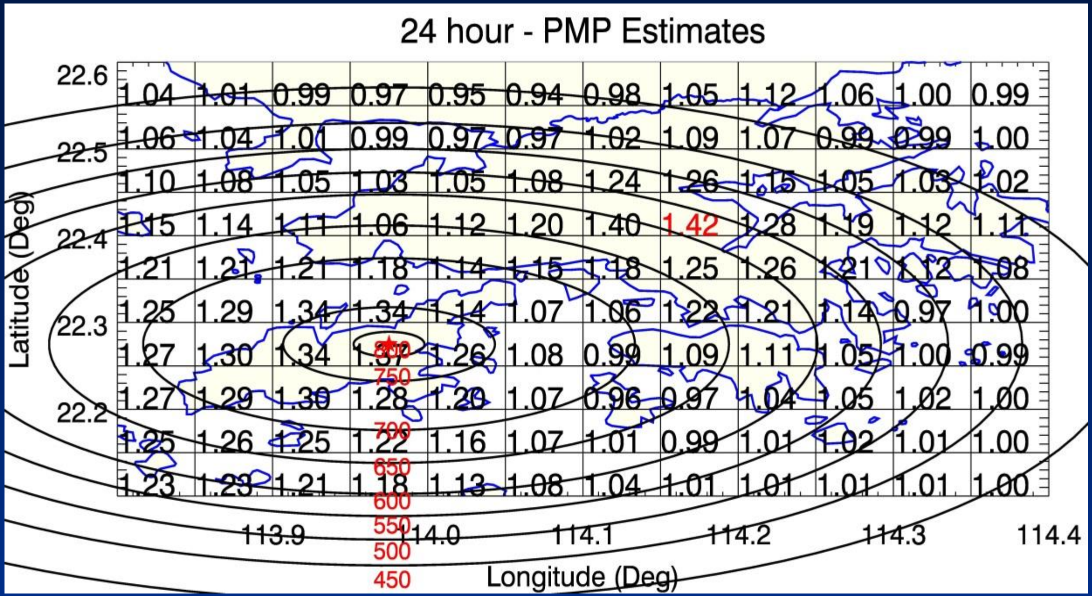
showing here is for the 4-hr Morakot pattern at resolution of 5kmx5km



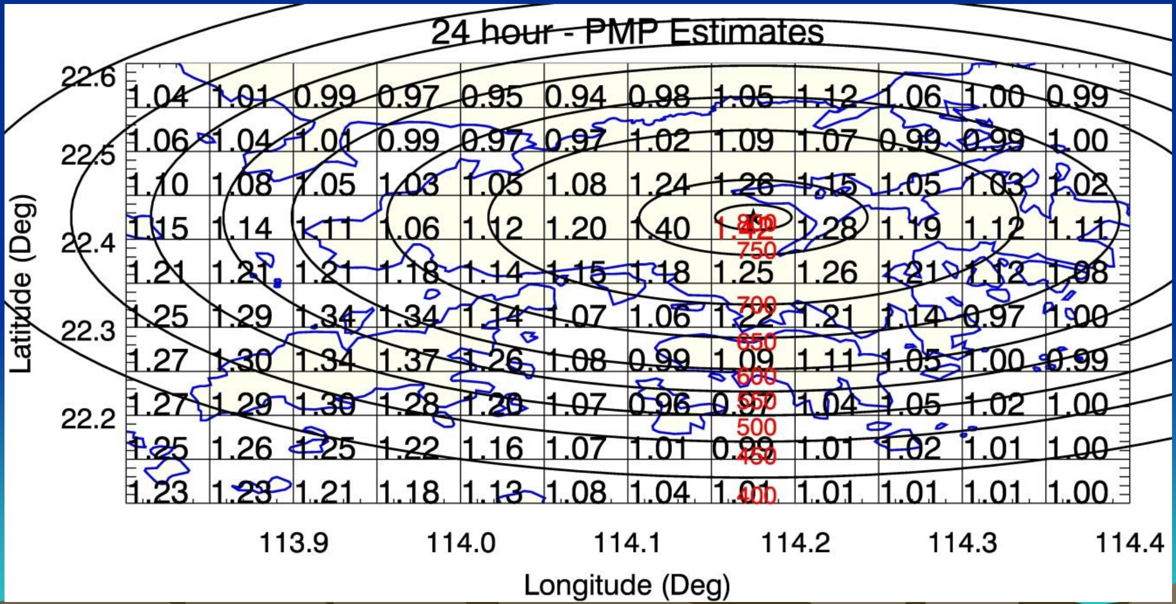
4-hr sub-mesh

Fig. 40 Illustration of cut-off sub-mesh of convergence pattern

E-W orientation with different center points （as example)



(Peak at Lantau)



(Peak at Tai Mo Shan)

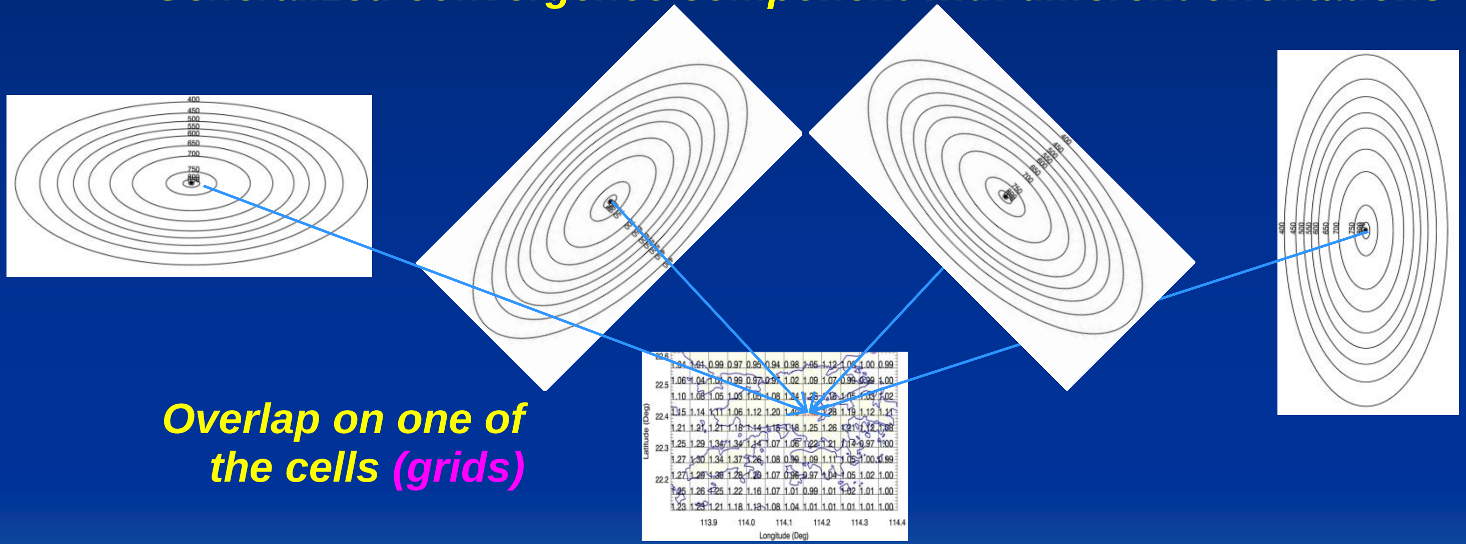
Fig. 41 Orientation of transposed convergence pattern (1)

Application of PMP to Landslide Risk Assessment

Approach：

- Theoretically, the generalised convergence component can be superimposed on (and centered at) each OIF grid cell of Hong Kong to generate an individual PMP estimate fraction for each cell

Generalized convergence component with different orientations

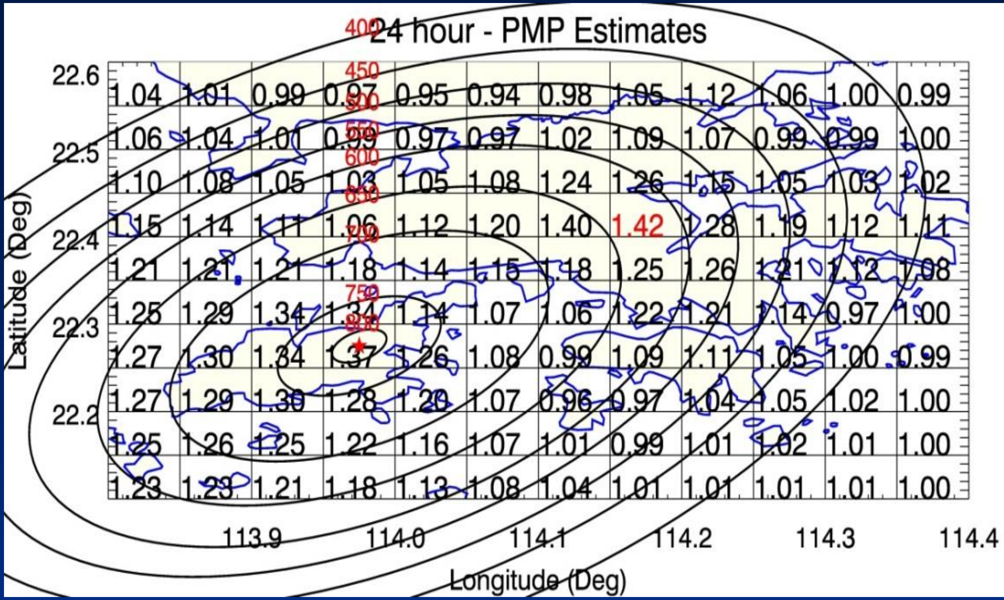


Orographic Intensification factors

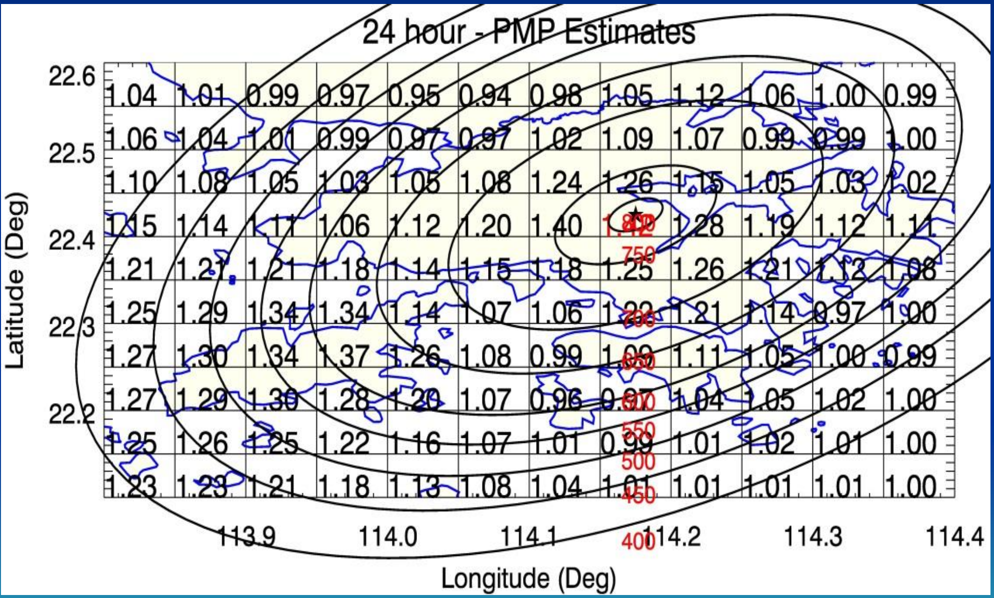
Then repeat the process for each individual cell

Orientation 45º – 24hr

(Embryonic PMP)



Centered at Lantau



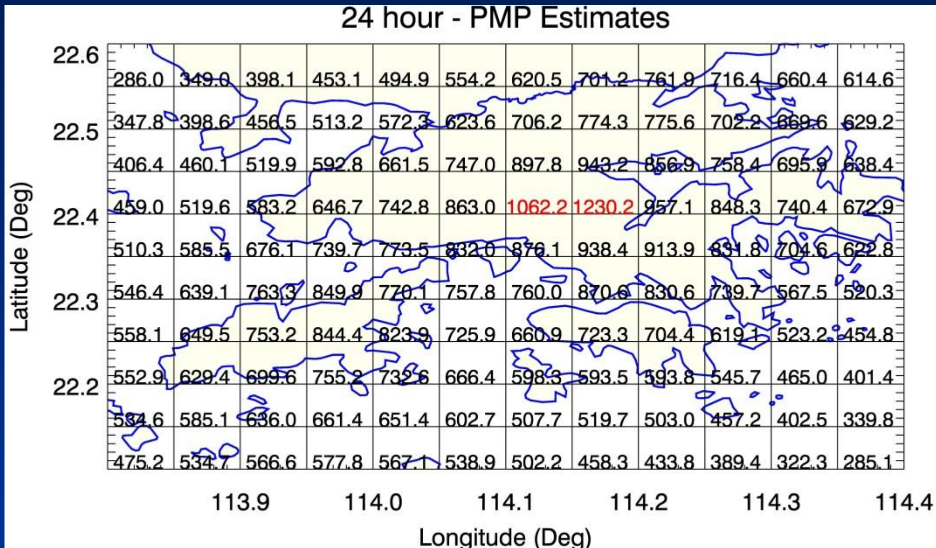
Centered at Tai Mo Shan

Fig. 46 Orientation of transposed convergence pattern (4)

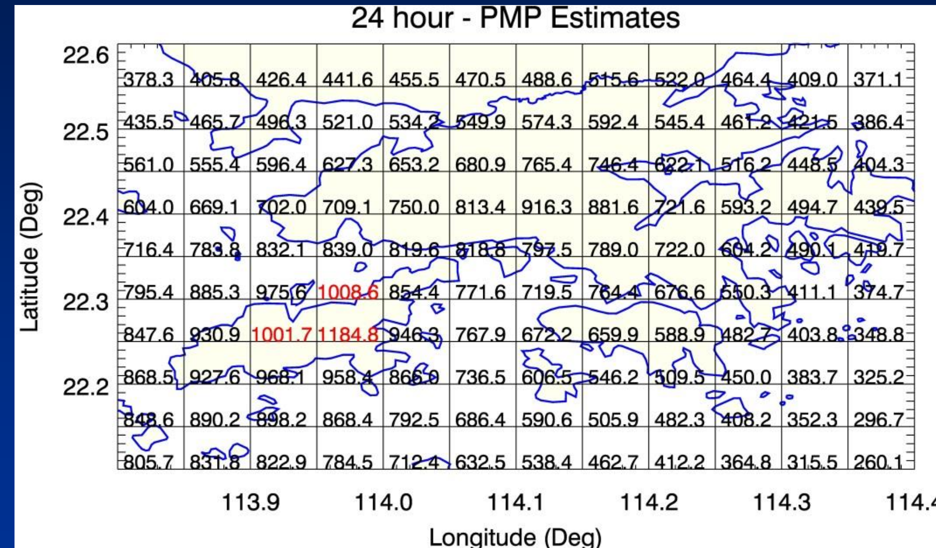
NE-SW orientation – 45º

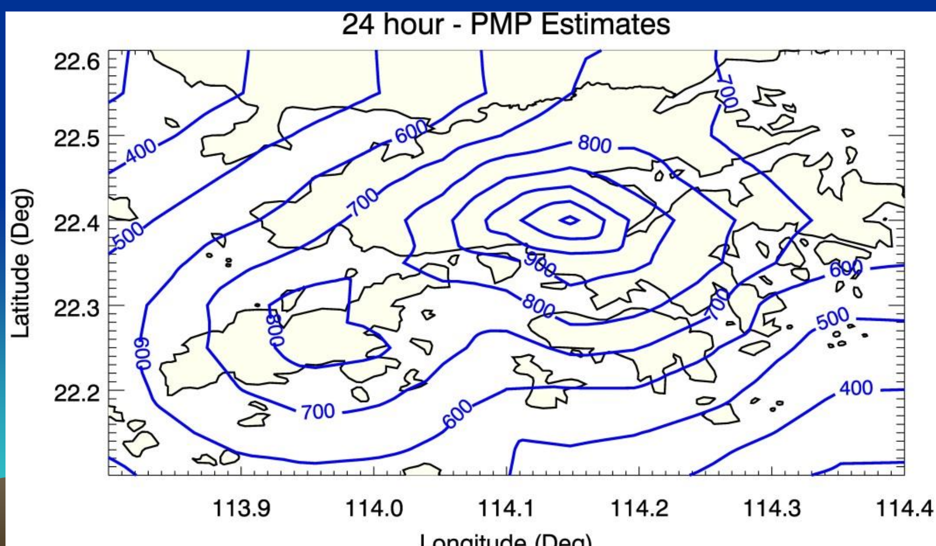
(Embryonic PMP)

Centered at Tai Mo Shan



Centered at Lantau





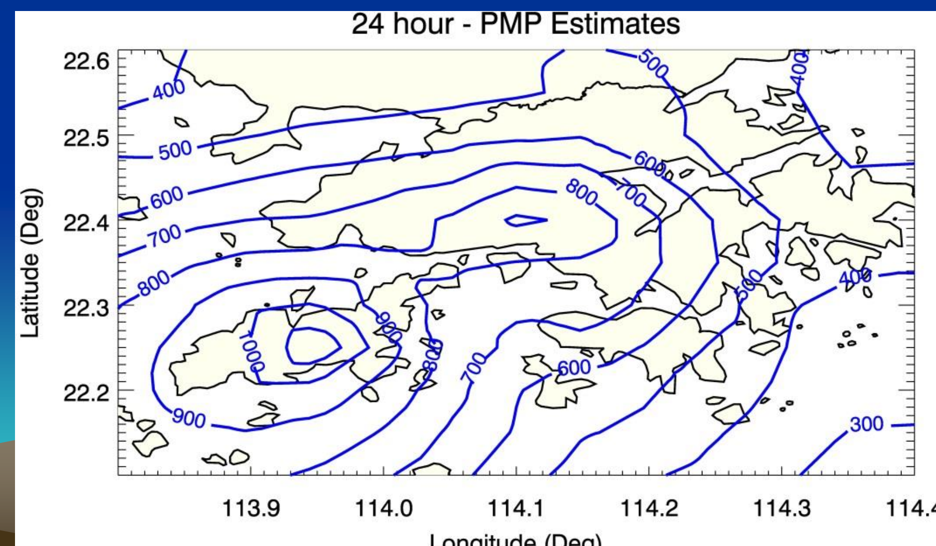


Fig. 47 Embryonic PMP for HK-2 (example only)

Depth-Area-Duration Curves （1）

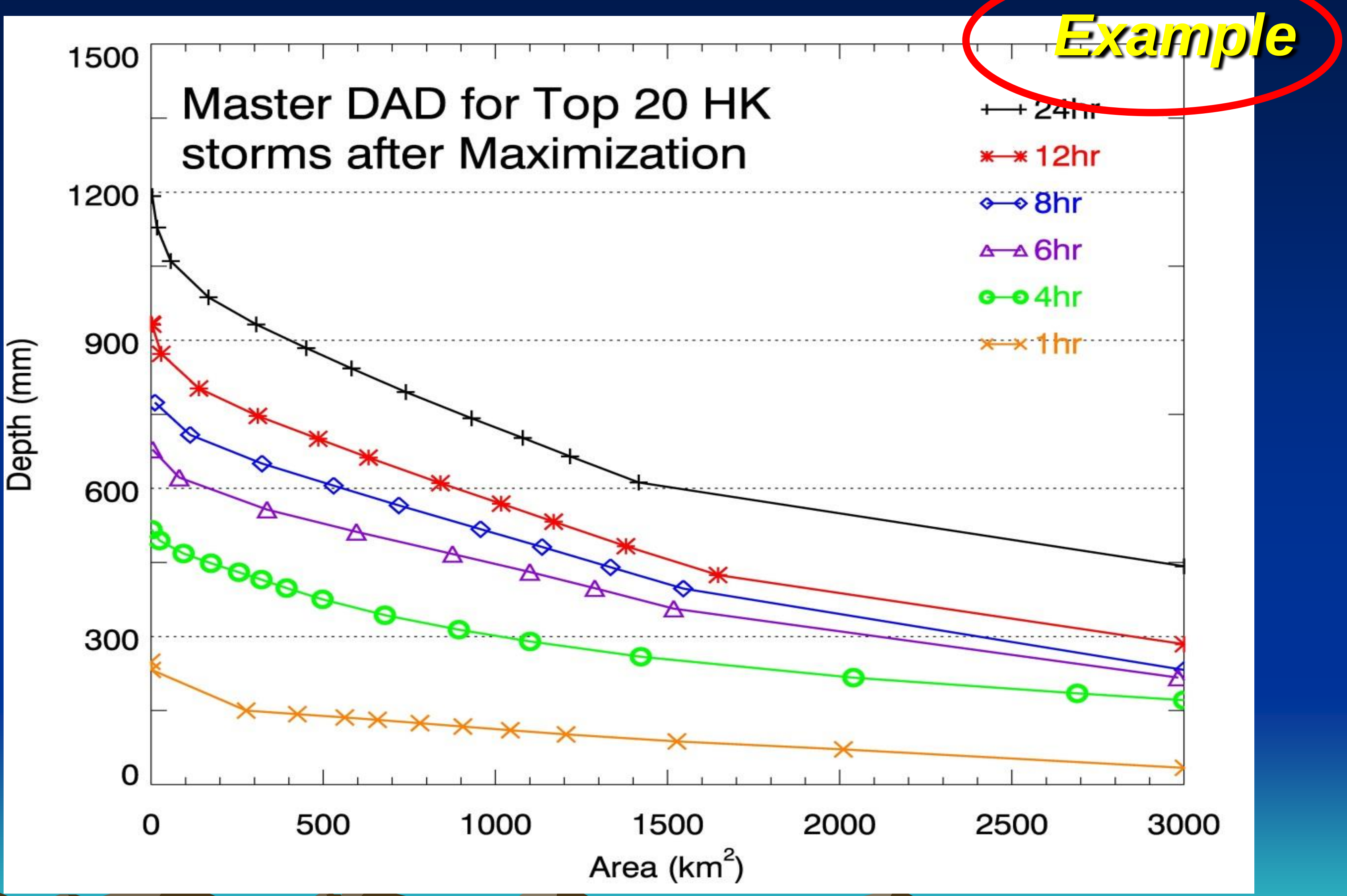


Fig. 48 DAD curve-1 (example only)

Depth-Area-Duration Curves （2）

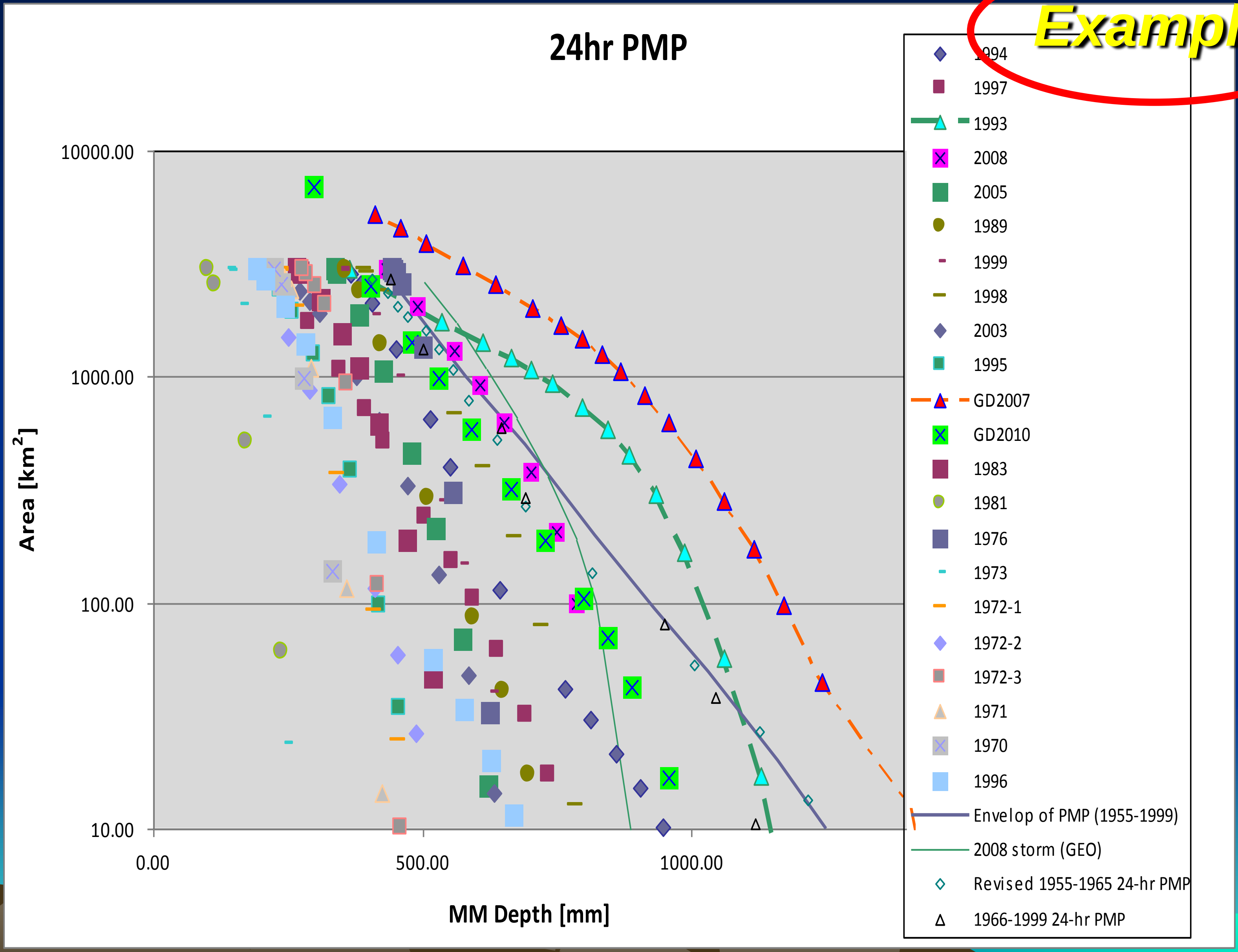


Fig. 49 DAD curve-2 (example only)

Moisture Maximization

Ratio of Moisture Maximization:

Ratio of moisture maximization for transposition

$r = W_m / W_r = W_{27.4} / W_{24} = 99.6 / 74.0 = 1.346$

in which, W_m is the historical maximum consistent dew point which is 27.4°C *in design area* while the W_r is the representative dew point, 24.0°C, for the Morakot storm *in target area*.

Statistical Approach (1)

PMP, X_{PMP}

$$X_{PMP} = \overline{X}_n + K_m \times S_n$$

where $\overline{X}_n$ the mean of the n maxima
S_n the standard deviation of the n maxima

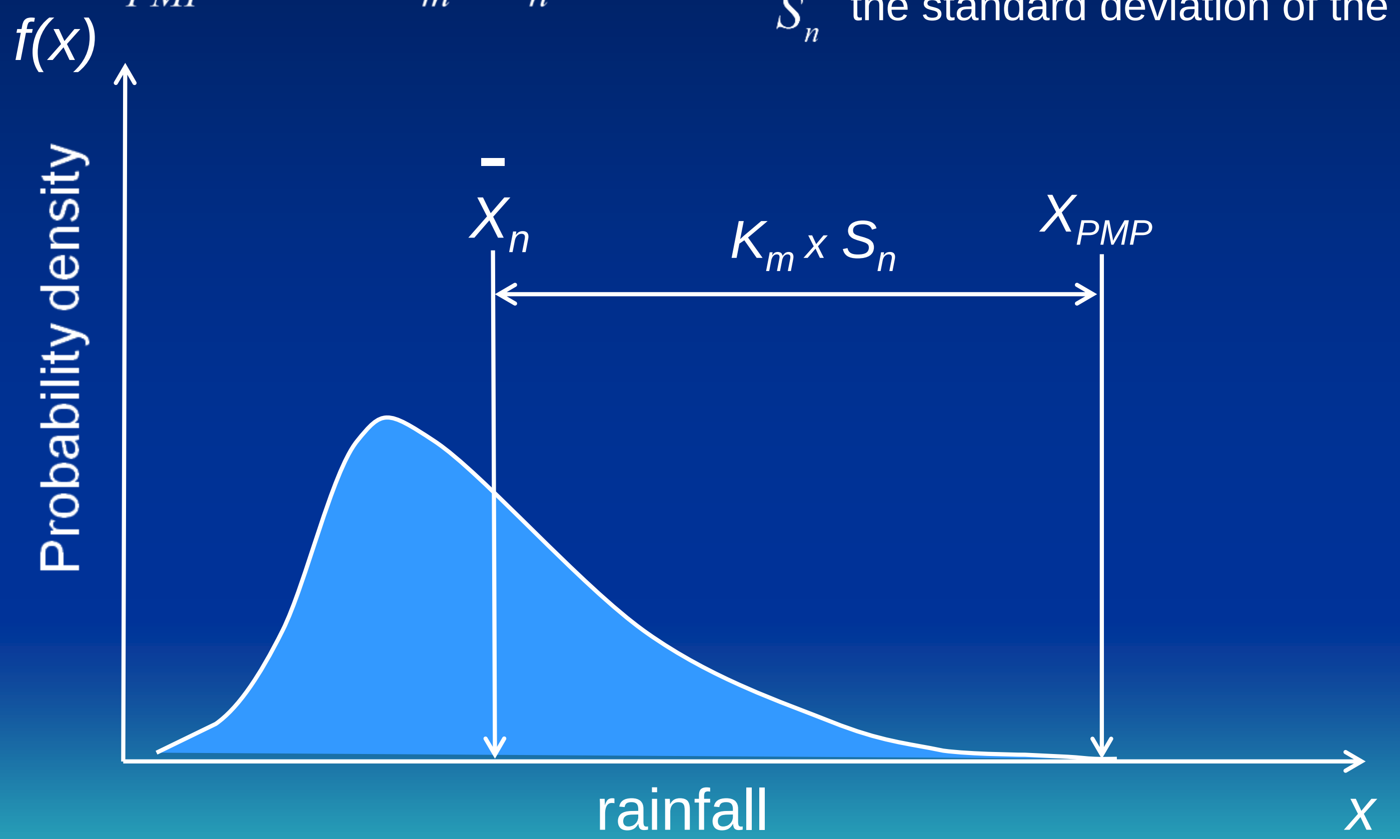


Fig. 50 Sketch for statistical approach to PMP (1)

Statistical Approach (2)

"Modified" Frequency Analysis

- "standard deviation", K_m, is added to the mean in the frequency equation

$$X_{PMP} = \bar{X}_n + K_m \times S_n = (1 + K_m \times C_{vn}) \times \bar{X}_n \longrightarrow X_{pmp} = \bar{X}_n + K_m \times S_n$$

where $\bar{X}_n$ and S_n are the mean and the standard deviation of the n maxima, C_{vn} is the coefficient of variation of the sample with n values

- calculated in a unique way that the maximum observed value (X_m) from the historical series will be omitted in the computation

$$K_m = \frac{(X_m - \bar{X}_{n-1})}{S_{n-1}} \longrightarrow X_m = \bar{X}_{n-1} + K_m \times S_{n-1}$$

Tricky

where $\bar{X}_{n-1}$ and S_{n-1} are the mean and the standard deviation of the rainfall series **from which the maximum record rainfall was omitted.**

Statistical Approach (3) – New development

Criteria to Check the Eligibility and Stability of Using the Method

- Beyond the WMO No. 1045
- The criterion of **minimum data size** of N_m

$$N_m = \phi_m^2 + 2$$

where ϕ_m is the maximum deviation from mean and is directly computed from the following equation,

$$\phi_m = \frac{(X_m - \overline{X}_n)}{S_n}$$

- The criterion of the **stable size** of N_s in terms of 10% relative error (*Lin, 1981; Lin & Vogel, 1993*)

$$N_s \geq 5.76 \times (\phi_m^2 + 2)$$

Quality of PMP Estimates

It depends upon:

1) Availability of data;

2) Depth of the study.

1: How to determine the lower limit of the integration of the pdf？

$$F(x)=\int_{-\infty}^{+\infty} f(x)dx=\int_{a}^{b} f(x)dx=\int_{?}^{?} f(x)dx=1$$

$$P_{Ex}=\int_{a}^{+\infty} f(x)dx=1$$

$$P_{Non}=\int_{-\infty}^{a} f(x)dx=0$$

Denominator = 0, computation crashed!

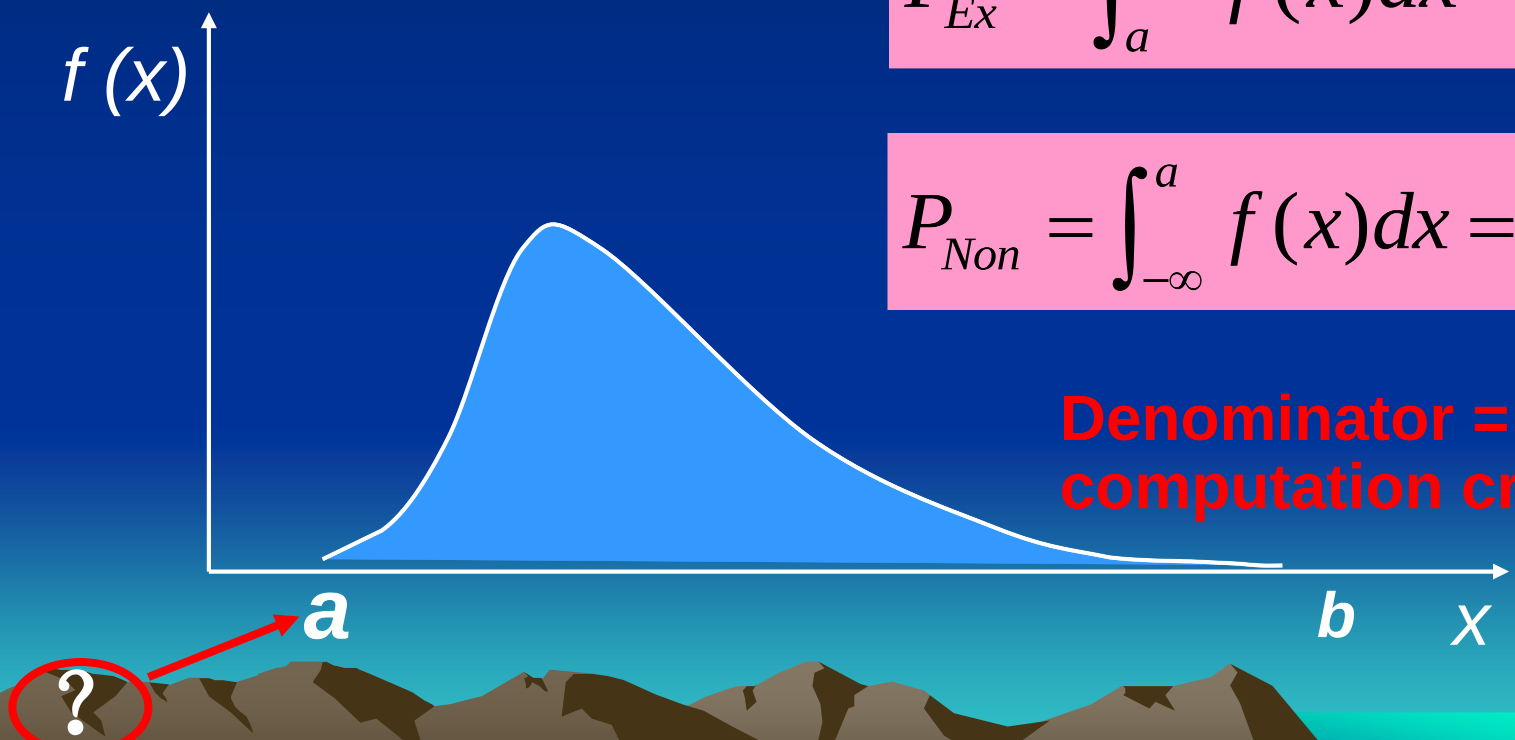


Fig. 52 Illustration of pdf curve (1)

Data sampling methods

- *Annual Maximum Series* (**AMS**)

  Annual Maximum Series (AMS) data consist of the largest event in each year, regardless of whether the second largest event in a year exceeds the largest events of other years.

- *Partial Duration Series* (**PDS**) *

  A partial duration series is a series of data which are selected so that their magnitude is greater than a predefined base value.

- *Annual Exceedance Series* (**AES**) *

  If the base value of the PDS is selected so that the number of values in the series is equal to the number of years of the record, the series is called an annual exceedance series. The AES may be regarded as a special case of the PDS. In the study, the PDS refers AES.

(* Ven Te Chow, *Applied Hydrology,* 1988 edition)

Exceedance frequencies of data (1)

- Location of the Semiarid study area

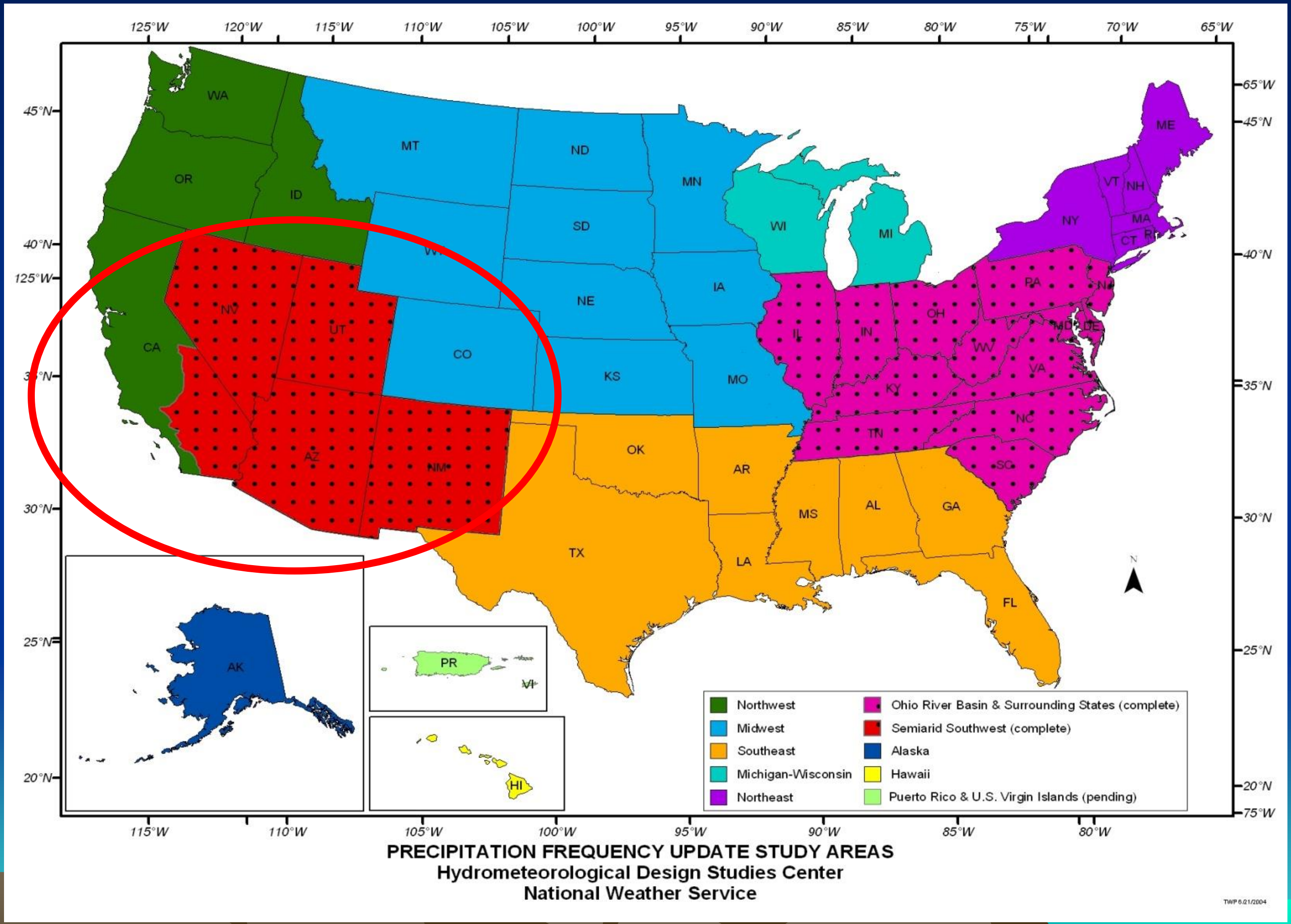


Fig. 53 SA data -- used for test of sampling methods

Exceedance frequencies of data (2)

- **Table 1** **Exceedance probabilities for region 1, SA**

Station ID	Data years	Return Period (R.P.) / Exceedance Probability (E.P.)					
		2-y	5-y	10-y	25-y	50-y	100-y
		0.5	0.2	0.1	0.04	0.02	0.01
04-0029	56	0.76	0.18	0.07	0.04	0.04	0.02
04-1476	53	0.64	0.26	0.13	0.06	0.04	0.04
04-1805	38	0.76	0.22	0.13	0.03	0.03	0
04-2964	48	0.66	0.21	0.04	0.04	0.04	0.02
04-4838	40	0.67	0.26	0.13	0.10	0.05	0.03
04-9053	69	0.68	0.25	0.09	0.03	0.01	0
35-2018	41	0.60	0.24	0.19	0.05	0.02	0.02
35-3232	30	0.56	0.16	0.10	0.07	0.03	0
35-5174	32	0.75	0.22	0.09	0.06	0.06	0
35-7354	67	0.66	0.20	0.11	0.05	0.03	0.02
35-8007	47	0.82	0.25	0.07	0	0	0
Average E. P.		***0.687***	***0.223***	***0.104***	***0.048***	***0.032***	***0.014***
Corresponding R.P.		***1.45-y***	***4.49-y***	***9.57-y***	***20.75-y***	***31.45-y***	***73.53-y***

Exceedance frequencies of data（3）

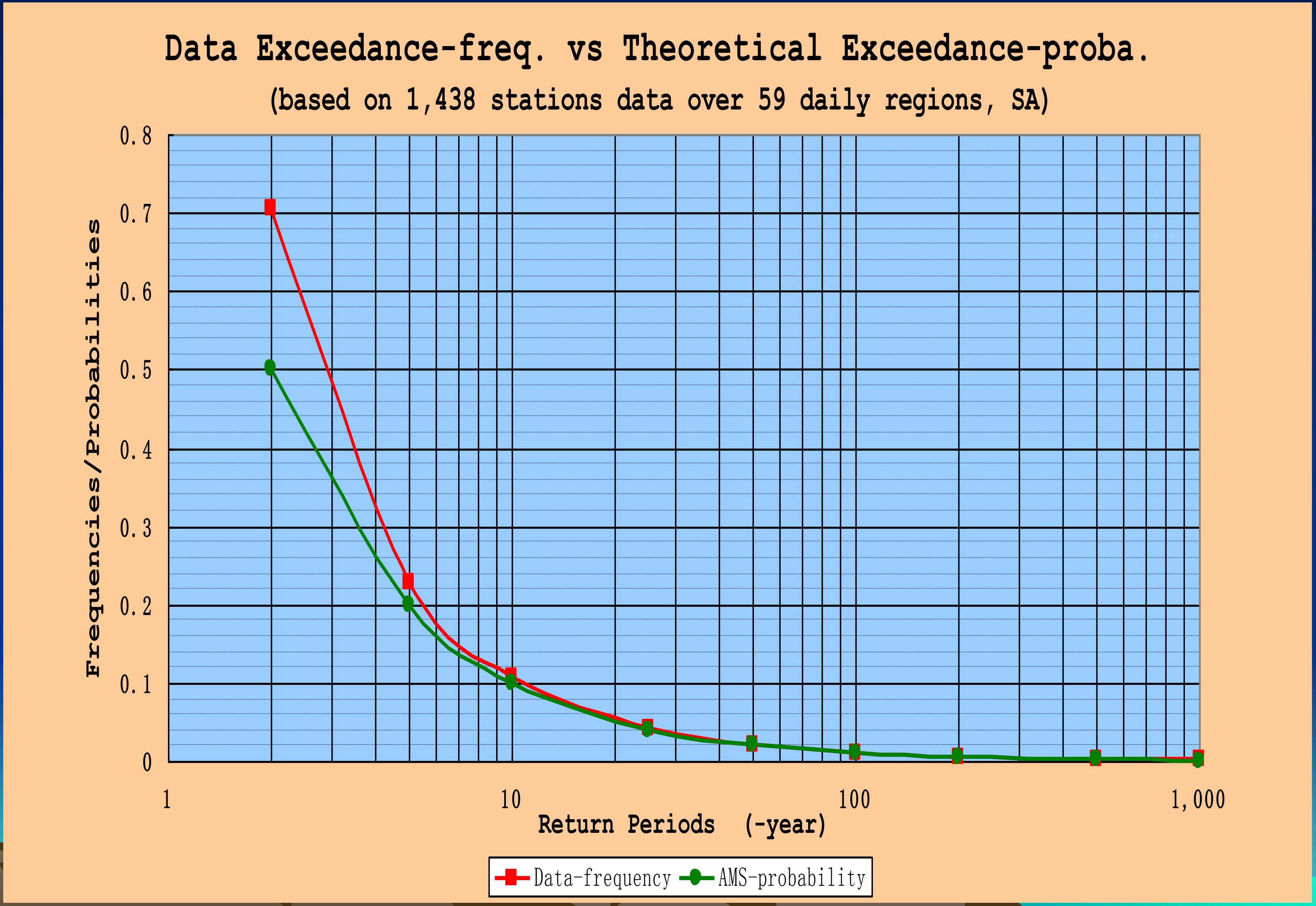


Fig. 54 Illustration for comparison of frequency to probability

Underestimated quantiles based on AMS

- It is clear from **Table 1** above:
  - The average exceedance frequencies of the 11 stations in the region 1 are 0.687, 0.223, 0.104, 0.032 and 0.014 for return periods of 2-y, 5-y, 10-y, 25-y, 50-y and 100-y, respectively.
  - The corresponding real return periods are calculated to be 1.45-y, 4.49-y, 9.57-y, 20.75-y, 31.45-y and 73.53-y.
- It is also clear from the Chart above:
  - The area averaged exceedance frequencies are higher than the corresponding analytical exceedance probabilities for 2-y through 100-y, particularly much higher for 2-y to 10-y.
- **Conclusion:**
  - ***Under current concept，quantiles were underestimated based on AMS particularly for 2~10-year。***

What is wrong?

- Obviously, the quantiles for frequent events, particularly 2-y thru 10-y, have been underestimated for long time under current estimation approach.
- The problem comes from **inconsistency** between the definition of the **return period** of quantiles and the data **sampling method** that creates the AMS data for frequency analysis to get the quantiles.
- The return period is defined for **an average time interval** in unit of year for x_T to occur over a large time period. It doesn't mean occurring once per each time interval.
- However, **the AMS takes only the largest event** in each year, regardless of whether the second largest event in a year exceeds the largest events of other years. Something (some high values) has been missed.

Relation (equation) of PDS-AMS

- Conversion of PDS-AMS:

$$T_{AES} = [\ln(\frac{T_{AMS}}{T_{AMS}-1})]^{-1}$$

(Ven Te Chow, 1964)

- or,

$$T_{AMS} = \frac{1}{1-e^{-\frac{1}{T_{AES}}}}$$

How to correct?

- Two ways to correct the underestimation:
  - To use the **AES** data in combination with the use of the exceedance probabilities listed in Table 2, i.e. **0.5, 0.2, 0.1, 0.04 and 0.02** for return periods of 2-y, 5-y, 10-y, 25-y and 50-y.
  - Or, to use the **AMS** data in combination with the use of the exceedance probabilities listed in Table 3, i.e. **0.3935, 0.1813, 0.0952, 0.0392 and 0.0198** for return periods of 2-y, 5-y, 10-y, 25-y and 50-y.
- **The two ways are deemed to be equivalent in quantiles estimation.**

Findings / Suggestions

- Quantiles based on AMS are underestimated；
- Concept of PDS or AES is in accordance with the Return Period；
- ***Recommend***: It is YES to continue to employ the AMS data but with adjustments of non-exceedance probabilities based on Ven Te Chow's equation of PDS-AMS。

Thus, 1-year event can be estimated

- Table 3 Return periods based on AES data

T_{AES} (-year)	T_{AMS} (-year)	$P_E = 1 / T_{AMS}$ *	$P_{NON} = 1 – 1 / T_{AMS}$*
1	1.58	0.6321	0.3679
2	2.54	0.3935	0.6065
5	5.52	0.1813	0.8187
10	10.51	0.0952	0.9048
25	25.50	0.0392	0.9608
50	50.50	0.0198	0.9802

*p_E stands for exceedance probability; p_{NON} stands for Non-exceedance probability.

2: How to determine the upper limit of the integration of the pdf？

$$F(x)=\int_{-\infty}^{+\infty} f(x)dx=\int_{a}^{b} f(x)dx=\int_{?}^{?} f(x)dx=1$$

$$P_{Ex}=P(X>b)=\int_{b}^{+\infty} f(x)dx=0$$

It means: the pdf should converge at b.

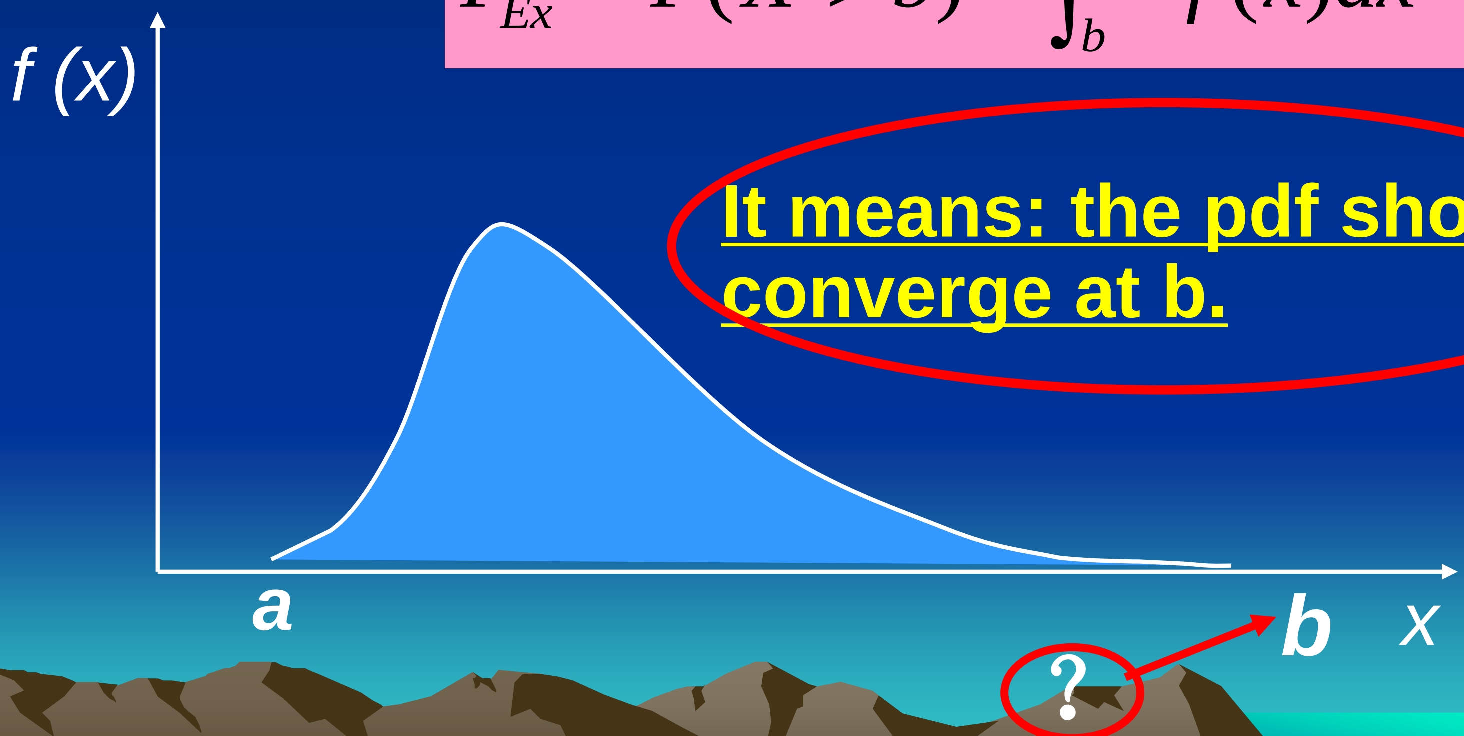


Fig. 55　Illustration of pdf curve (2)

Can we do?

In other words:

What is the probability of an estimated PMP?

In current textbooks it assumes:

- All quantiles are normally distributed ➔ *leading to divergence of upper tail*

Against reality

However，my studies say:
"No, not the case!"

1. Quantiles vary asymmetrically
2. Around 25-50yr – symmetrical variation
3. Quantiles < 25-50yr – positively skewed
4. Quantiles > 25-50yr – negatively skewed

➔***leading to convergence of upper tail***

（My investigations of a great number of AMS precipitation data in the U.S. and China support my findings; see below Figs. 56、57、58）

Findings (Results) over 84 Regions, OH

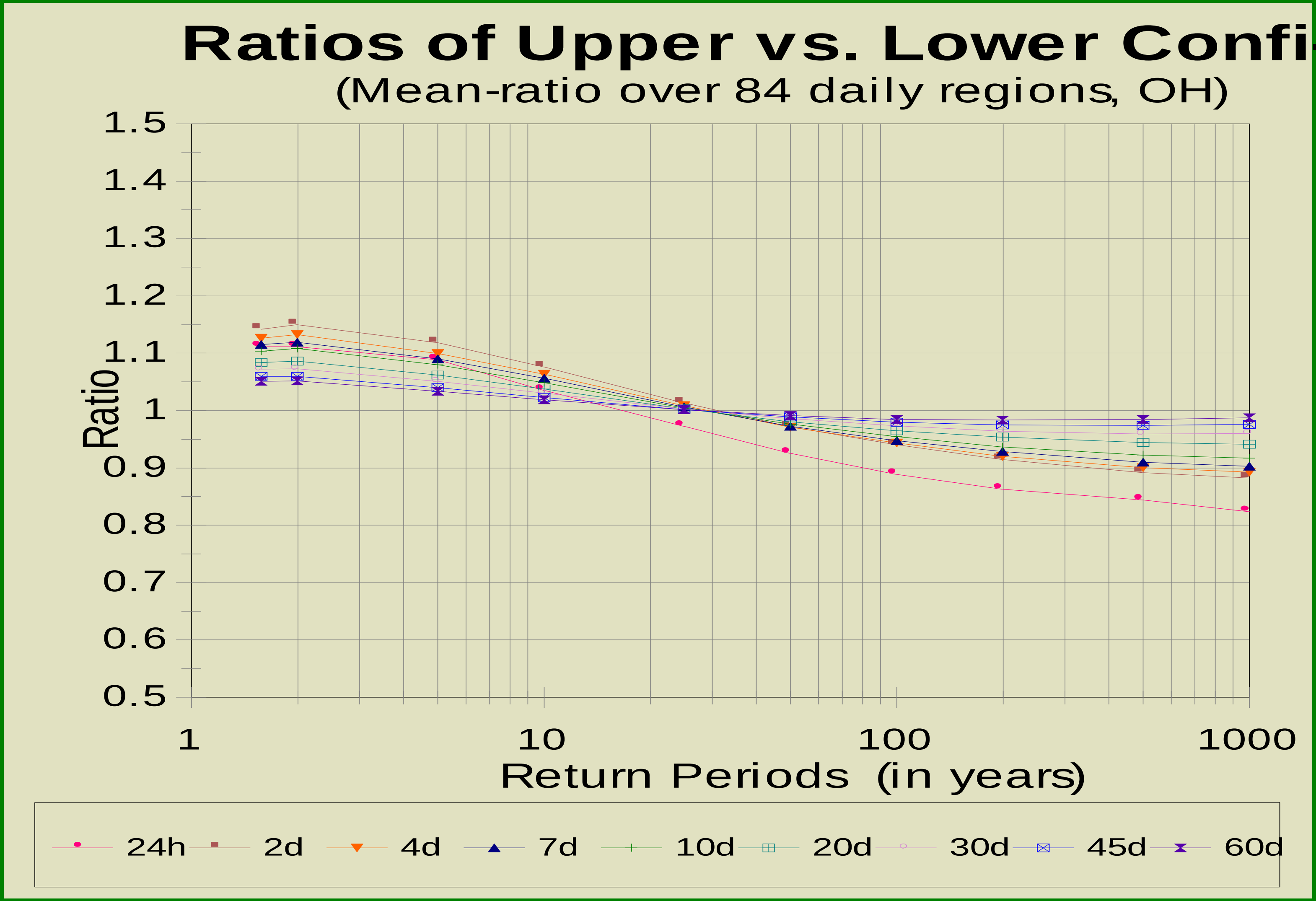


Fig. 56 Rations of (upper vs lower) for Ohio River Basin

Findings (Results) over 59 Regions, SA

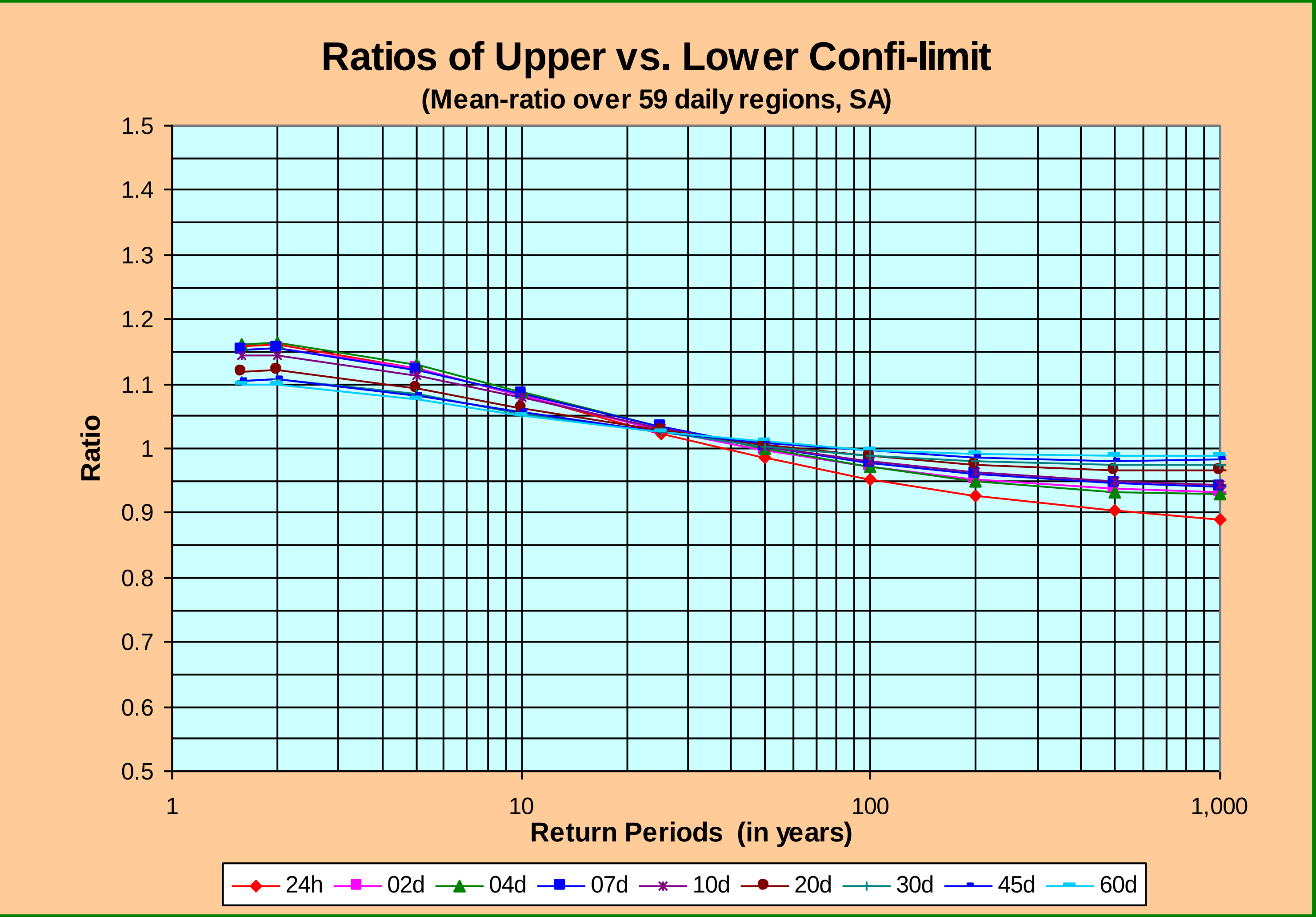
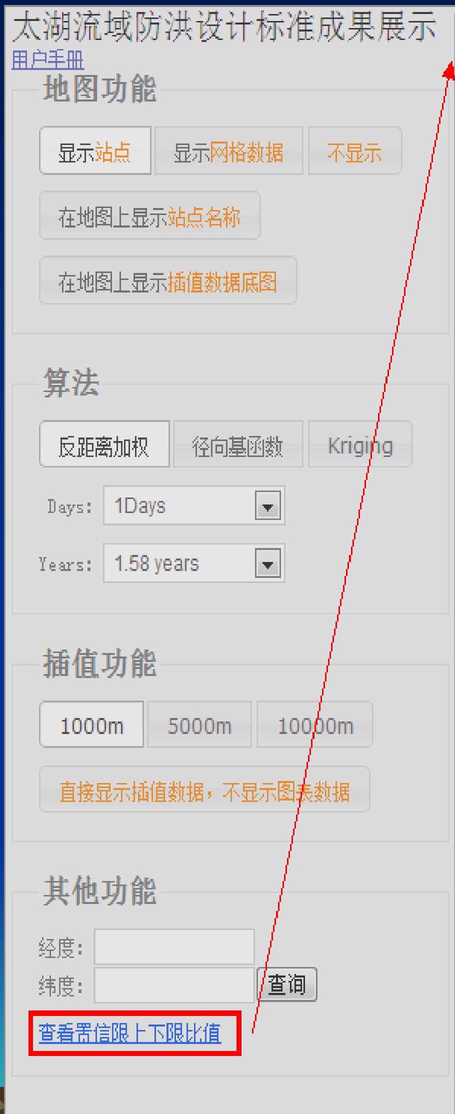


Fig. 57 Rations of (upper vs lower) for SW Semiarid U.S.

Findings (Results) over 8 Regions, Taihu



置信限上下限比值

时段长	重现期(Y)mm									
	Y1_58	Y2	Y5	Y10	Y25	Y50	Y100	Y200	Y500	Y1000
1天	1.24	1.24	1.19	1.11	1.03	0.98	0.95	0.92	0.90	0.90
3天	1.22	1.22	1.16	1.10	1.04	1.00	0.97	0.96	0.96	0.96
7天	1.21	1.21	1.16	1.10	1.03	1.00	0.98	0.97	0.97	0.97
10天	1.17	1.17	1.12	1.08	1.02	0.99	0.98	0.98	0.99	1.00
太湖流域平均	1.21	1.21	1.16	1.10	1.03	0.99	0.97	0.96	0.95	0.96

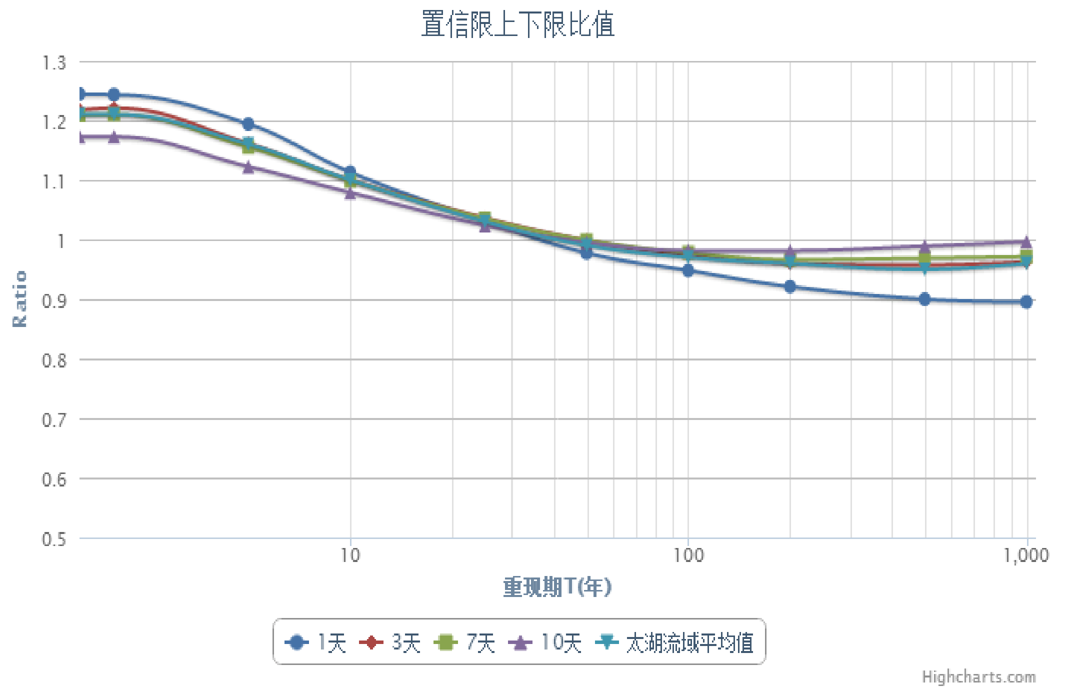


Fig. 58 Rations of (upper vs lower) for Taihu Lake

These Studies indicate that:

Upper tail of frequency distribution tends to converge

These evidences suggest that

the upper tail of the probability distribution should converge to a certain value by an asymptote.

Conclusion: **Estimation of the upper limit of integration of the PDF is *doable***

$$\int_{-\infty}^{+\infty} f(x)dx = 1$$

$$\int_{?}^{?} f(x)dx = 1$$

$$\int_{a}^{b} f(x)dx = 1 \longrightarrow \textbf{OK}$$

Uncertainties of quantiles

Thus, ***the frequency analysis and the PMP study can be unified***, *tested each other*, complemented and no longer fighting against each other – **this may change the entire world of the hydrologic design studies.** ***Amazing!***

水文概率分布曲线的上端尾部应该是以渐近线的形式收敛于某个确定的值。

Wow !

概率密度函数积分上限b？

物理意义 – 概率密度函数的上（右）端点

理论意义 – 概率密度函数分布上端是收敛的

Just half-way

学术价值 – 百年难题（把频率分析和PMP估算统一起来）

学术意义 – 使得理论分析与常识一致（**降雨有上限！**）

应用价值 – 工程设计安全、**不确定（风险）分析**、造价投资

Est. 1989

AHMRI

水文气象学院

南京信息工程大学

Acknowledgements

1. NOAA of the U.S.: *Precipitation Frequency Atlases Update project* (complete);
2. MWR of China: *Application of Regional L-Moments Method to Flood-Mitigation Planning* (#201001047, complete);
3. MWR of China: *Impact of Climate Change on PMP Estimation and the Countermeasures to Flood-Mitigation* (#201101033, complete);
4. HKSAR Government GEO: *PMP Estimation for Hong Kong* (complete);

The End

Thank you!