Study on Probable Maximum Precipitation under Concerns over Climate Change

--因应气候变化的可能最大降水估算

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Current Status of PMP Estimation

1. **There is no much progress in methodology on PMP estimation since publication of "*Manual for Estimation of PMP*"** (*Second edition, WMO, 1986, Geneva*) **though the 3rd edition has been released in 2009.**

2. **Confusion：Is it a hydrologic matter or meteorological matter?**

3. **Two new issues：**

   1）Impact of climate change on PMP estimation

   2）What's the probability of a PMP estimate？

Definition of PMP （1）

“Probable maximum precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location *at a particular time of year*, with no allowance made for long-term climate trends.” *(3rd edition, 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*、在特定地点和给定时段内、在某一设计流域上或者给定暴雨面积下，气象上所可能降下的最大雨量；这个降水量是不考虑气侯的长期变化趋势。（*WMO “PMP估算手册”，第三版*）

Definition of PMP （2）

Actually, there are two interrelated definitions in the context：

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

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

PMP 的定义 （2）

实际上是包含了两个暨不同又互为依存的定义：

1. 可能最大降水定义为*一年的特定时间中*、在特定地点和给定时段内、在某一设计流域上，气象上所可能降下的最大雨量；这个降水量是不考虑气侯的长期变化趋势。
（水文的定义）

2. 可能最大降水定义为*一年的特定时间中*、在特定地点和给定时段内、在给定暴雨面积下，气象象上所可能降下的最大雨量；这个降水量是不考虑气侯的长期变化趋势。
（气象的定义）

Definition of PMP （3）

Arguments：

1. **The objective of a PMP estimate is to calculate the Probable Maximum Flood (PMF) in design study for an engineering project in a given watershed；**

2. **PMP estimation should be taken into account of storm orientation adjustments onto a watershed with specific size and shape；**

3. **The phrase of "***at a particular time of Year*" is irrelevant or less important to PMP estimate.

PMP 的定义（3）

由于：

1. PMP估算是直接为推求PMF（可能最大洪水）为工程设计服务的；
2. PMP估算应考虑不同流域形状而进行暴雨图的主轴方向订正（Storm orientation adjustment)。
3. 强调一年的特定时刻没有实际意义。

Definition of PMP （4）

Thus, we suggest a definition of PMP (hydrometeorologically):
因此，我们建议新的定义(水文气象途径）如下：

Probable maximum precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed at a particular location，with no allowance made for long-term climate trends. *（Special study on “PMP Estimation under Consideration over Climate Change”, MWR of China, 2011)*

可能最大降水定义为在特定地点和给定时段内、在某一设计流域上，气象上所可能降下的最大雨量；这个降水量是不考虑气侯的长期变化趋势。*(中国科技部、水利部行业专项《气候变化对PMP估算影响研究》， 2011-2013）*

PMP Estimation Methodology -- International Practice (1)

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

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

PMP Estimation Methodology -- International Practice (2)

New developments:

Use of Radar data and GIS technology to help in describing the temporal and spatial distributions of rainfall to enhance the accuracy of D-A-D (Depth-Area-Duration) curves. (in the U.S.)

Tasks of a PMP Estimation (1)

(PMP Estimation for Hong Kong as example)

1. Data collection

   a) Historical rainfall data (daily & hourly annual Maximum Series, AMS, the most) for raingauges in both HK and the vicinity, southern Guangdong Province) with geographical info for these raingauges;

   b) Historical tropical cyclones and Typhoons that have visited the HK and the vicinity;

   c) 6-hour increment of Dew Point observations in HK;

   d) Historical rainfall data (daily & hourly AMS) for the Taiwan Island (southern part, the much needed) if Morakot event is targeted to be transposed.

   e) Others (most are used for comparisons)

Tasks of a PMP Estimation (2)

(PMP Estimation for Hong Kong as example)

2. Statistical approach as a rough and quick estimation

•Hershfield, D.M. (1961), *Estimating the Probable Maximum Precipitation*, ASCE Proceedings, Vol.87, pp. 99 – 106

•林炳章，*统计估算法在可能最大降水研究中的应用，*《河海大学学报》，1981年1月，南京

•B. Lin, J. Vogel, *A New Look at the Statistical Estimation of the PMP*, ASCE Proceedings, Session S25, pp. 629-634, June 1993, San Francisco

Tasks of a PMP Estimation (3)

(PMP Estimation for Hong Kong as example)

3. Storm transposition (used in tropical mountainous regions)

- Storm survey from a nearby geographical region is preferable (typhoon-prone SE Asia areas)
- Schwarz (1972) suggested storm data from continents could be combined to develop reliable PMP estimates (Mekong River case 1970; Daguangba case 1987; Australia case 1985) based upon the similarity and occurrence of the tropical cyclones
- Knowledge of storm thermo- & dynamics and synoptic analysis

Tasks of a PMP Estimation (4)

(PMP Estimation for Hong Kong as example)

4. Transposition adjustments – **Storm Separation Technique**

(1) Laminar flow model (an idealized orographic precipitation model assuming the airflow to be laminar and does not provide reliable results because of its assumption and lack of data, 1961 & 1966 for California PMP) – Assumption & data **?**

(2) Storm separation based on ratio of 100-year frequency values between non- and orographic areas, NOAA 1973) – More subjective, no temporal distribution

Tasks of a PMP Estimation (5)

(PMP Estimation for Hong Kong as example)

5. Transposition adjustments – **Storm Separation Technique** (cont'd.)

(3) 林炳章，*分时段地形增强因子法在山区PMP估算中的应用*，《河海大学学报》，Vol.16, No.3, June 1988 (A peer-reviewed paper published after completion of a World Bank sponsored project; award-winning paper)

(4) B. Lin, *The Step-Duration-Orographic-Intensification-Factors-Method* (SDOIFM) (WMO-No.1045, Manual on Estimation of PMP 6.2.5, *PMP Estimation for the Daguangba Project in Hainan Island, China*, pp. 175-180, June 2010) – More objective and detailed but need quality data in plenty

Tasks of a PMP Estimation (6)

(PMP Estimation for Hong Kong as example)

6. Step by step for transposition of Morakot's:

(1) Development of the SDOIFs for the Alison terrain area in southern Taiwan

(2) Separation of Morakot storm rainfalls into convergence and orographic components by the Alison's SDOIFs

(3) Transpose the convergence component of Morakot's from Taiwan Island to H.K. area

(4) Development of the SDOIFs for the local H. K. terrain area

(5) Combine the Morakot's convergence component with the local orographic component by means of the local SDOIFs

Tasks of a PMP Estimation (7)

(PMP Estimation for Hong Kong as example)

7. Transposition adjustment 1

– moisture maximization adjustment for relocation

$$R_2 = R_1\left(\frac{W_2}{W_1}\right)$$

R_1 – storm rainfall adjusted for transposition

R_2 – obversed storm rainfall to be transposed

W_1 – precipitable water at observed storm location

W_2 – max precipitable water at design location

Tasks of a PMP Estimation (8)

(PMP Estimation for Hong Kong as example)

8. Transposition adjustment 2
– storm orientation adjustment

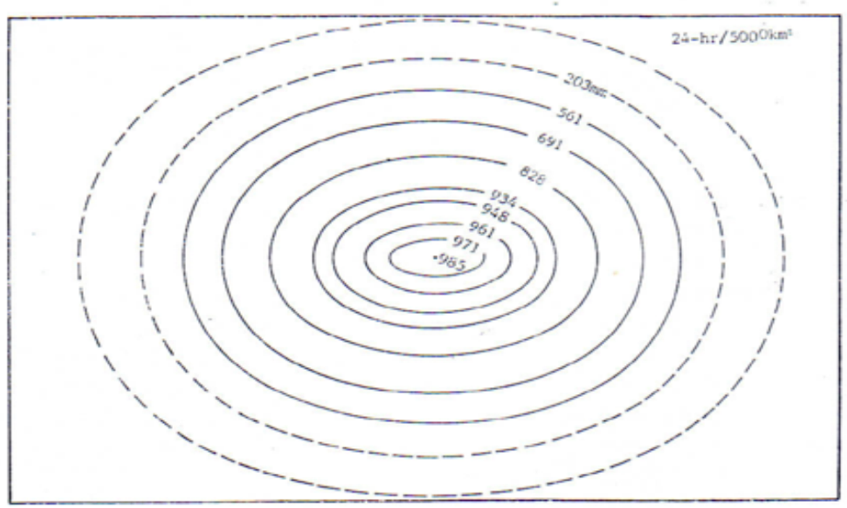

Fig. 6.25 Isohyetal Map of 24h, 5,000km2 PMP for Non-Orographic Regions in the Changhuajiang River Basin [Lin Bin-Zhang, 1988]

Convergence component pattern of storm

Tasks of a PMP Estimation (9)

(PMP Estimation for Hong Kong as example)

9. What is the probability of the estimated PMP? – Compare the PMP with the precipitation frequency analysis (FA)

- Introduction of the Regional L-moments Analysis, state-of-the-art technology in FA (Lin B. et al, EWRI2006, Omaha)
- Progress of the uncertainties of the FA
- Clue to help judge the reasonability of the PMP estimates (New progress/findings)

Tasks of a PMP Estimation (10)

(PMP Estimation for Hong Kong as example)

10. Take comprehensive comparison in many ways in addition to the check of reasonability/rationality mentioned above :

- The observed extreme rainfall records in the vicinity
- The PMP estimates in the neighboring areas
- The world rainfall records

Summary for PMP Estimation in East Asian Typhoon-prone Region

*Storm transposition in terrain area

- Comprehensive storm survey/analysis
- Selection of target storm
- Storm separation technique
- Transpose only convergence component
- Transposition adjustments
- Target Morakot Typhoon storm if it is determined to be transposed to design area
- Comprehensive comparison of the PMP estimate

Keep in Mind on PMP Estimation

1. PMP is an engineering design study issue.
2. Current knowledge of storm mechanism and rainfall efficiency remains insuficient to allow precise evaluation of extreme precipitation. Therefore, PMP estimates are considered approximations.
3. No standardized procedure used to PMP estimation.
4. Accuracy and reliability of a PMP estimate depends upon the amount & quality of hydrome data and the depth of analysis.
5. Investigators should understand well both hydrology and meteorology.
6. Investigators should understand well both frequency analysis and PMP estimation.
7. No way to verify the accuracy of a PMP estimate. (multi-approaches; comparisons are much needed!)

Key Considerations to Storm Transposition in E Asia

1. Morakot Typhoon storm of Aug. 7-10 2009 is targeted
2. Storm Separation technique – ***SDOIF method***

   (Developed by B. Lin in 1988; MWR of China, Standards for Hydrologic Design Studies, 1995; WMO No-1045, *Manual on Estimation of PMP,* 2009)

Pattern of non-orographic component

(Example of Daguangba Project; WMO No-1045, 2009)

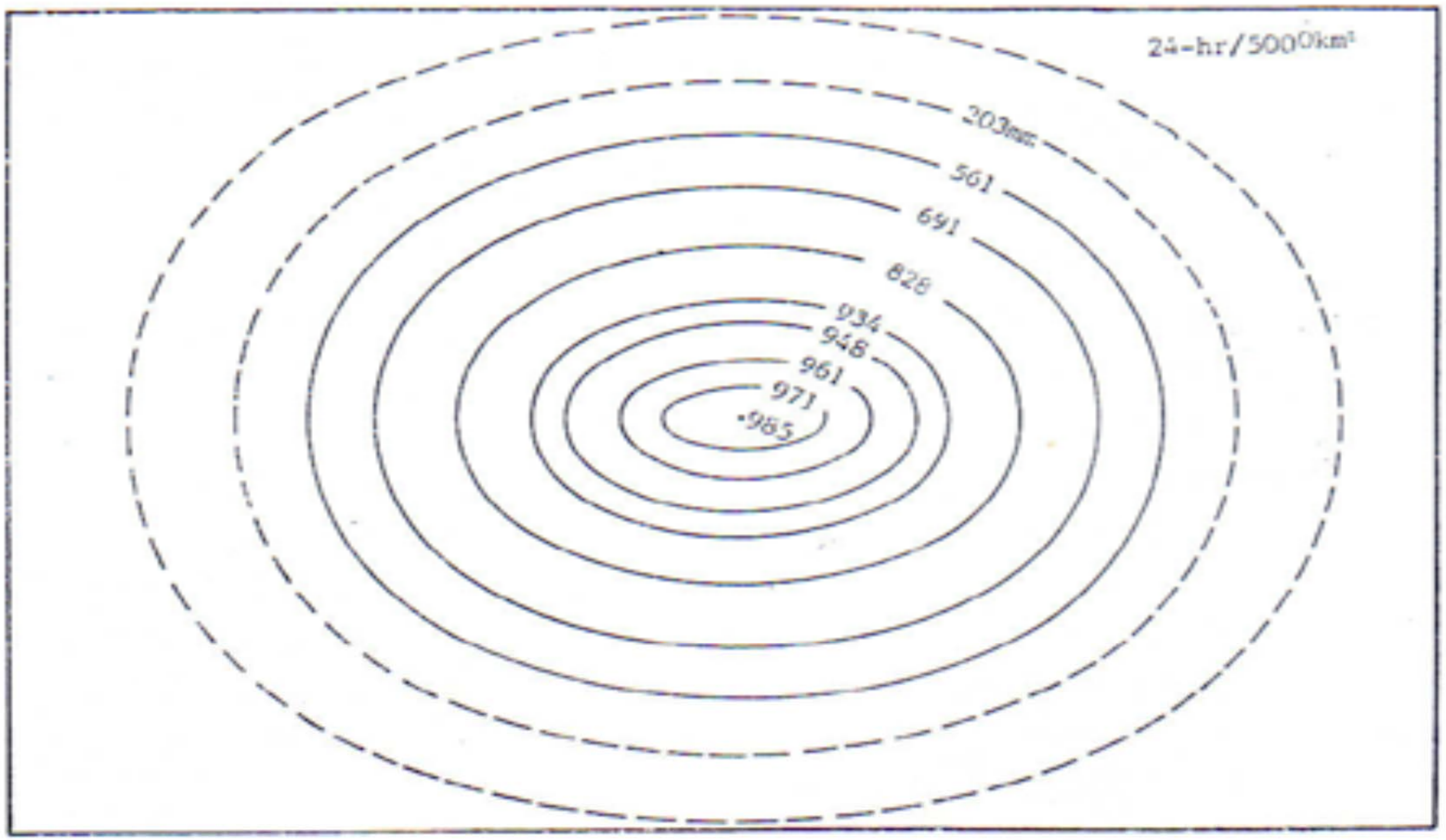

Fig. 6.25 Isohyetal Map of 24h, 5,000km2 PMP for Non-Orographic Regions in the Changhuajiang River Basin [Lin Bin-Zhang, 1988]

Table- Comprehensive Adjustment Coefficient for 24-hour Storms (Example of Daguangba Project on Hainan Island, WMO No-1045, 2009)

Y-axis	X-axis										
	1	2	3	4	5	6	7	8	9	10	11
1	1.04	1.09	1.15	1.27	1.38	1.55	1.08	1.10	1.27	1.42	1.08
2	1.00	1.05	1.21	1.48	1.65	1.22	1.08	1.13	1.02	1.06	1.10
3	1.03	0.96	1.00	1.39	1.38	1.03	0.98	1.00	1.07	1.28	1.15
4	1.28	1.27	1.12	1.11	1.10	0.96	0.99	1.00	1.09	1.06	1.31
5	1.72	1.84	1.10	0.98	0.91	1.10	1.16	1.09	1.07	0.97	1.18
6	1.44	1.13	1.02	1.12	1.12	1.11	1.13	1.16	0.90	0.84	0.84
7	1.02	0.81	0.78	1.20	1.22	1.12	1.13	1.15	1.11	0.84	0.85

24-h PMP Estimate Isohyets Pattern

(Example of Daguangba Project; WMO No-1045, 2009)

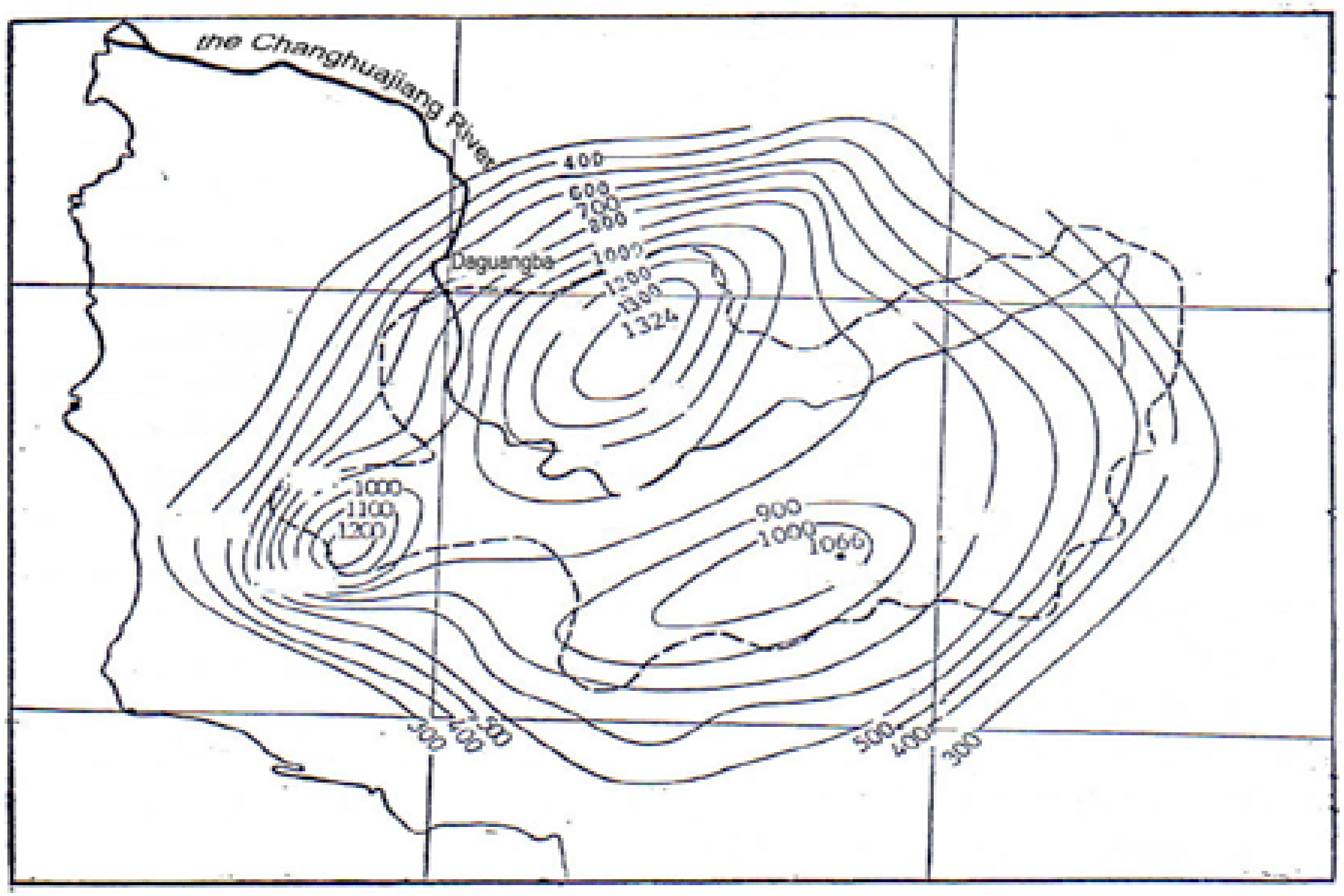

Fig. 6.26 Storm Isoline Map of 24h PMP for the Changhuajiang River Basin on Hainan Island

[Lin Bin-Zhang, 1988]

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**

(*1,624 mm in Alishan of central Taiwan according to Dr. Kung Chen-Shan of SINOTECH Engineering Services, Nanjing, Oct 2010)

A 1,000-y Event of Typhoon Morakot Storm Rainfall ?

Lessons/findings learned 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

Other Outstanding Storms

1. 1996 Herb (贺伯）Typhoon

   -- 1748 mm/24-hr at Alishan（阿里山）*

2. 2004 Aere（艾莉）Typhoon

   -- 1154 mm/24-hr at Madala (马达拉）*

3. 2005 Haitang (海棠）Typhoon

   -- 1254 mm/24-hr at Weiliao-shan (尾寮山）*

*（Presentation of Dr. Kung Chen-Shan of SINOTECH Engineering Services at NUIST, Nanjing, Oct 2010)

Two issues

1. Impact of Climate Change on PMP

1. There is "*no allowance made for long-term climate trends*" (*WMO, 1986 & 2009*).
2. An Australian research concluded that "*So far, we cannot confirm that PMP estimates will definitely increase under a changing climate* " (*Australian BOM research report, Hydrometeorological Advisory Service, 2009*)

1. Impact of Climate Change on PMP

(Continued)

However, practically:

1). To affect the precipitable water: SST in E. sea increases by 1º C from 24º C to 25º C, PMP in C. China will increase roughly by 9% under assumption that the maximum moisture availability is derived from the 12-hour persisting dew points based on a rough calculation on precipitable water in saturated pseudo-adiabatic atmosphere.

2). Effect on the selection of the transposed storm: The occurrence of a severe rainfall storm in the nearby region could alter the PMP estimates in this area. A good example is Morakot Typhoon of Aug 7-10, 2009

2. A Pioneer Study

What is the probability of a PMP estimate?

Uncertainties of quantiles (1)

The current assumption:

- All quantiles are normally distributed

<u>**Uncertainties of quantiles**</u> <u>(2)</u>

<u>My findings</u>:

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

L-Moments

Definition: L-moments are expectations of certain linear combinations of order statistics (Hosking, 1989)

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

$$\lambda_1 = EX$$

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

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

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

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

Application of RLM to Precipitation Frequency Analysis in the U.S. (1)

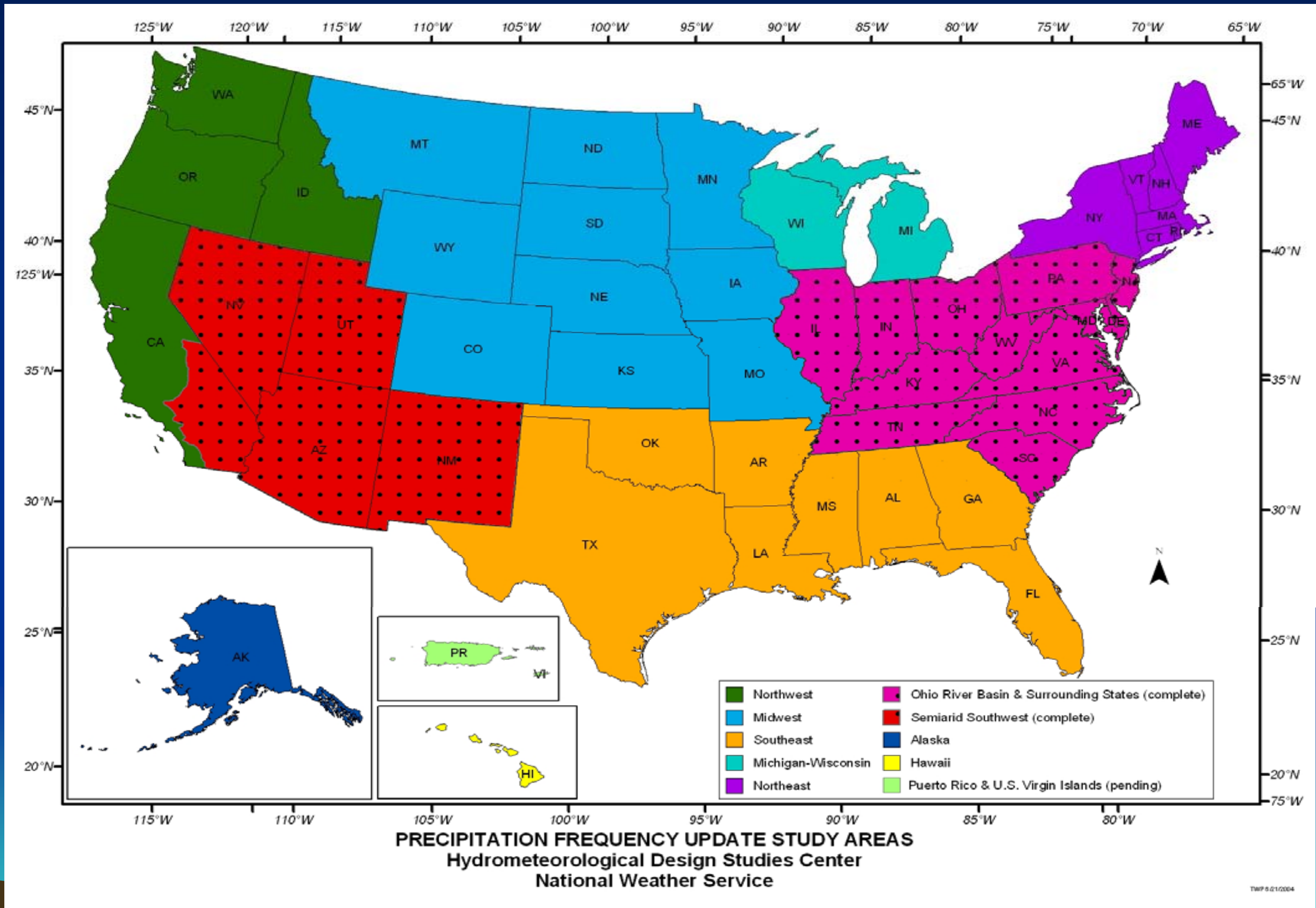

Fig. Sketch of regionalization of the U.S.

Application of RLM to Precipitation Frequency Analysis in the U.S. (2)

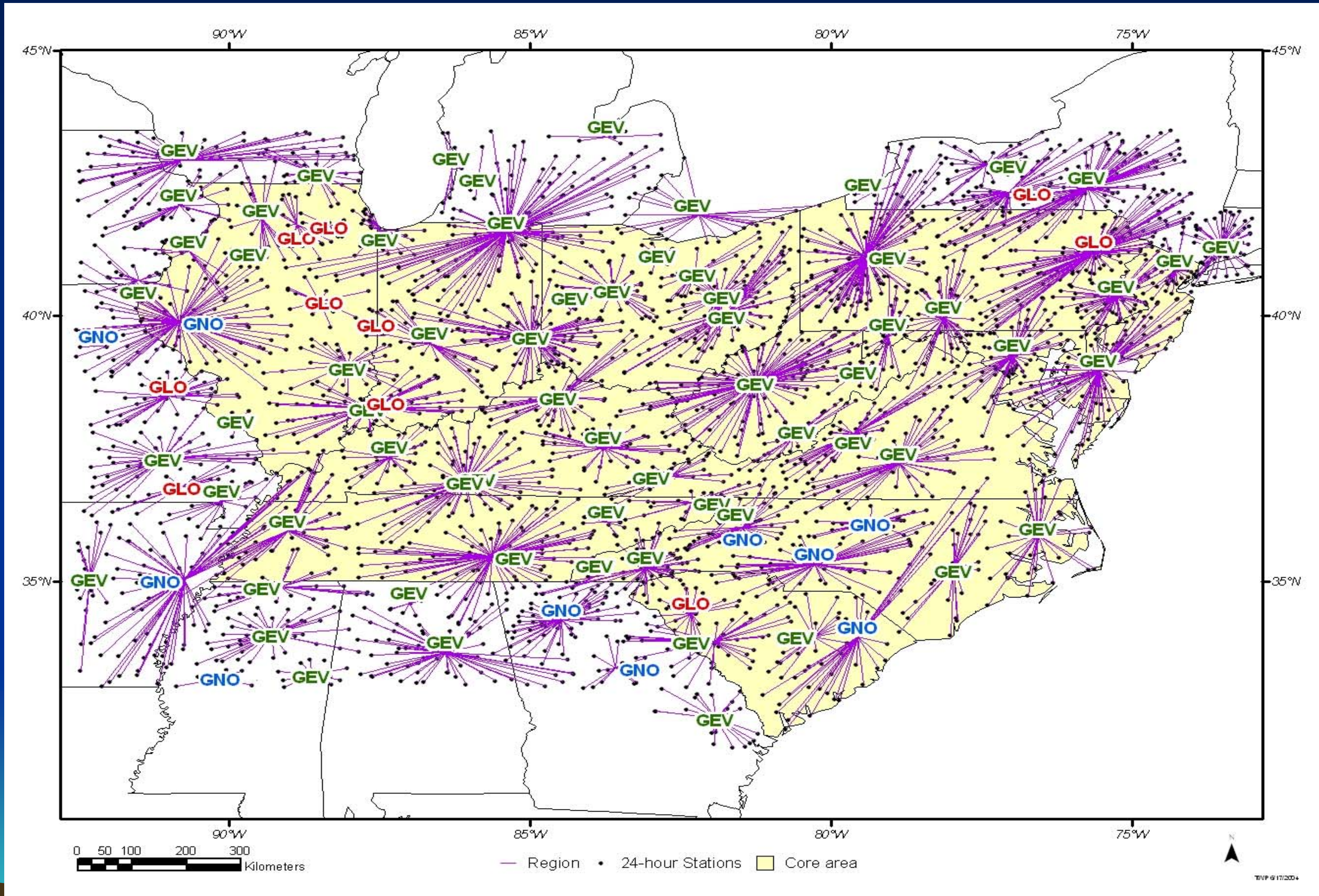

Fig. 84-region of regionalization for Ohio River Basin

Uncertainties of quantiles (3)

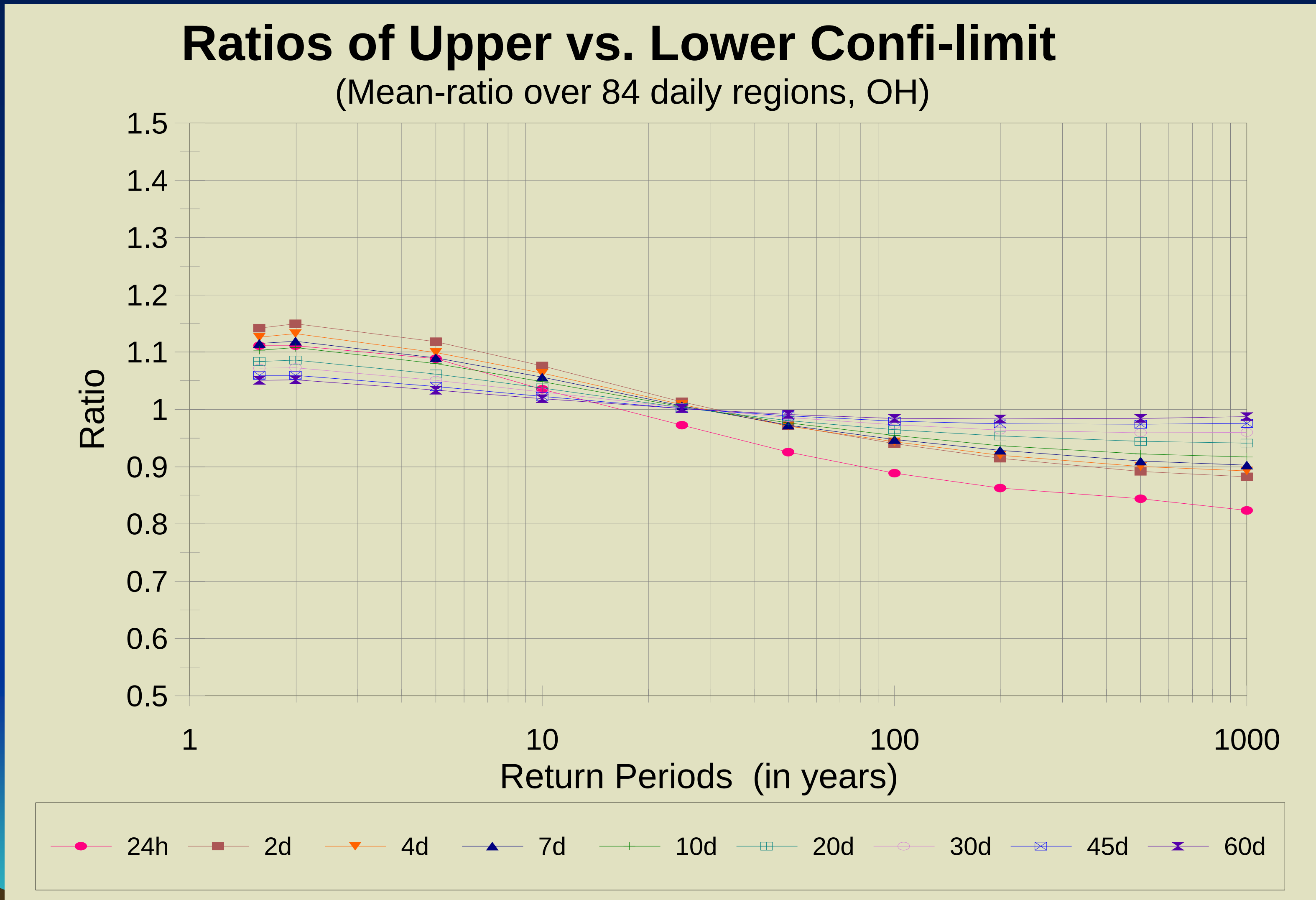

Fig. 8 Rations of confidence intervals for Ohio River Basin

Uncertainties of quantiles (4)

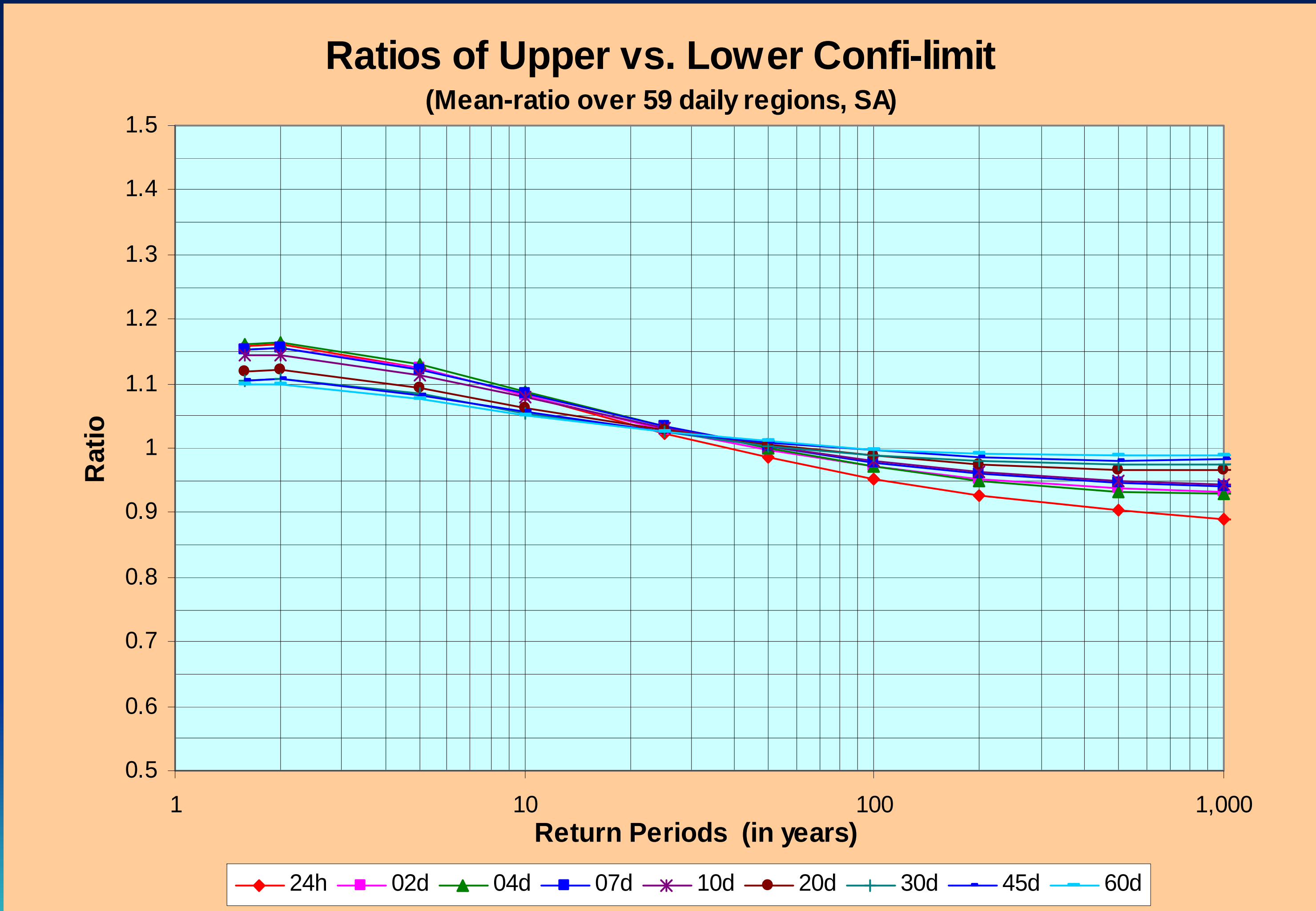

Fig. 9 Rations of confidence intervals for SW Semiarid U.S.

Uncertainties of quantiles (5)

These findings provide for the first time a scientific clue to some extent: how the PMP estimates look like as upper limit in the hydrologic engineering design studies in terms of comparability with frequency analysis results.

Uncertainties of quantiles (6)

这些研究成果第一次提供了科学线索：从工程水文设计的观点来看，作为降雨上限的PMP估计值与频率分析估计值的可比性如何。

The End

Thank you

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