定量降水預報的現況與展望

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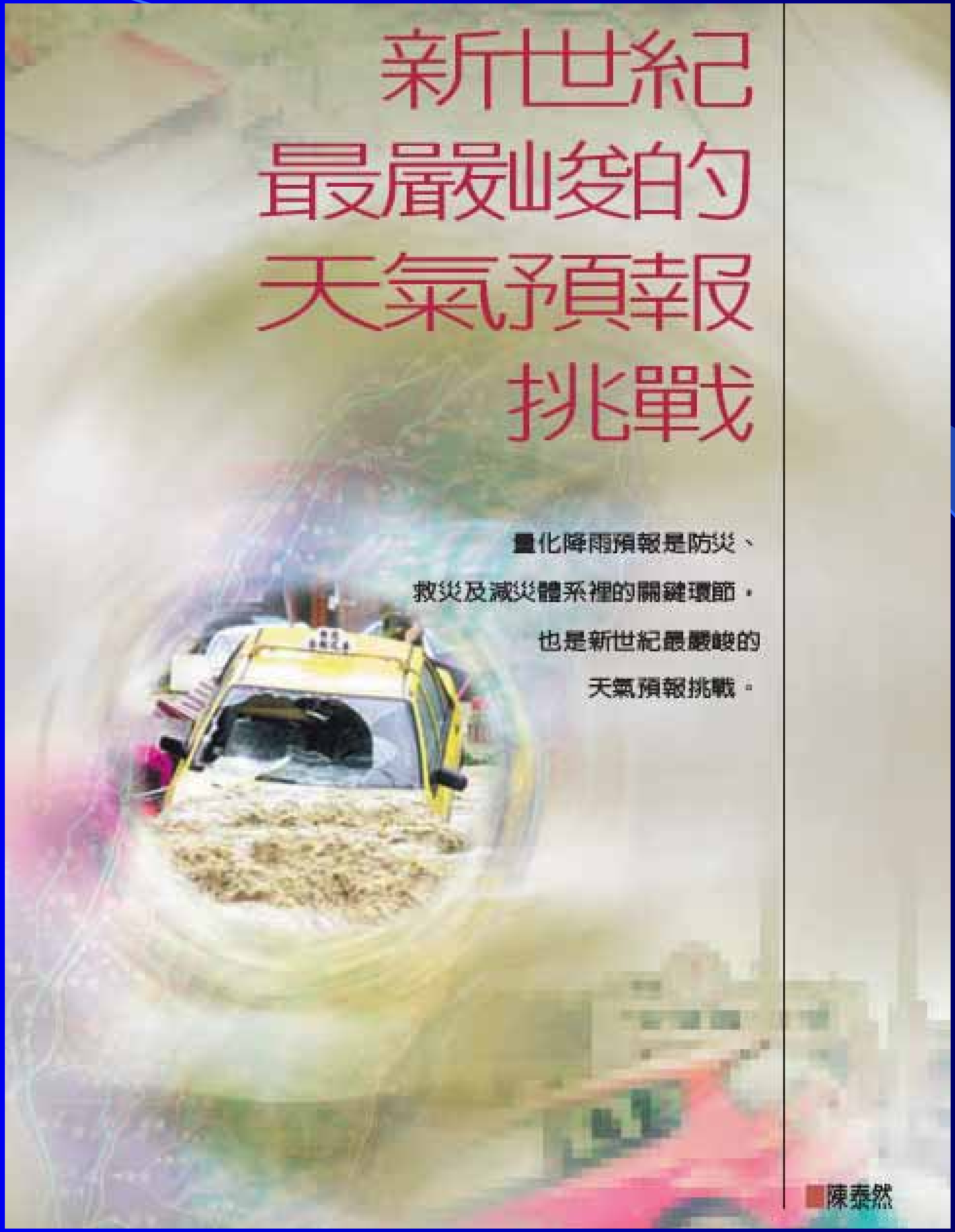
民國94年12月21日
中央氣象局專題報告


新世紀
最嚴峻的
天氣預報
挑戰
量化降雨預報是防災、
救災及減災體系裡的關鍵環節，
也是新世紀最嚴峻的
天氣預報挑戰。
陳泰然

定量降水預報

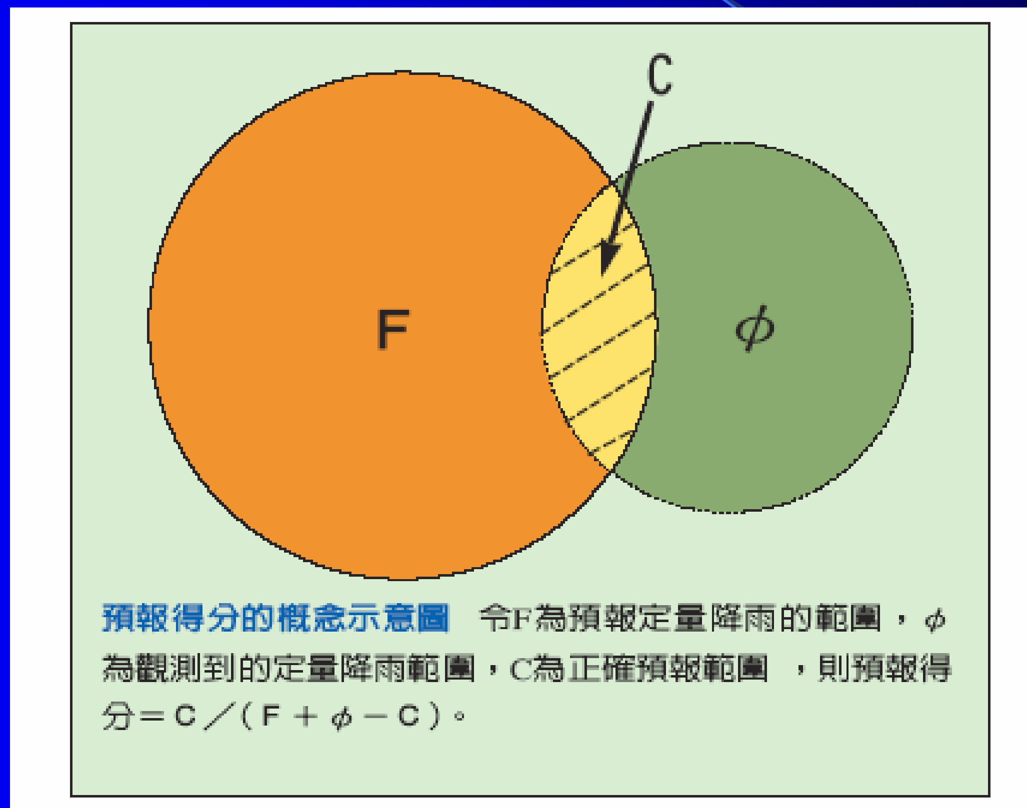
- 為國家防災, 減災, 救災體系關鍵環節的氣象問題(陳泰然 2003)
- 台灣地區的災變天氣:颱風, 梅雨, 寒潮, 乾旱(民國67年台灣地區災變天氣研討會)
- 1983~1993台灣地區中尺度實驗計畫(Taiwan Area Mesoscale EXperiment; TAMEX)

定量降水預報

- 全省自動雨量站網的建立 (1987)
- 全省都卜勒雷達網聯的建立 (2001)
- 大雨,豪雨,特大豪雨預報發佈(2004)
- 24小時定量降水預報產品公佈(2006)

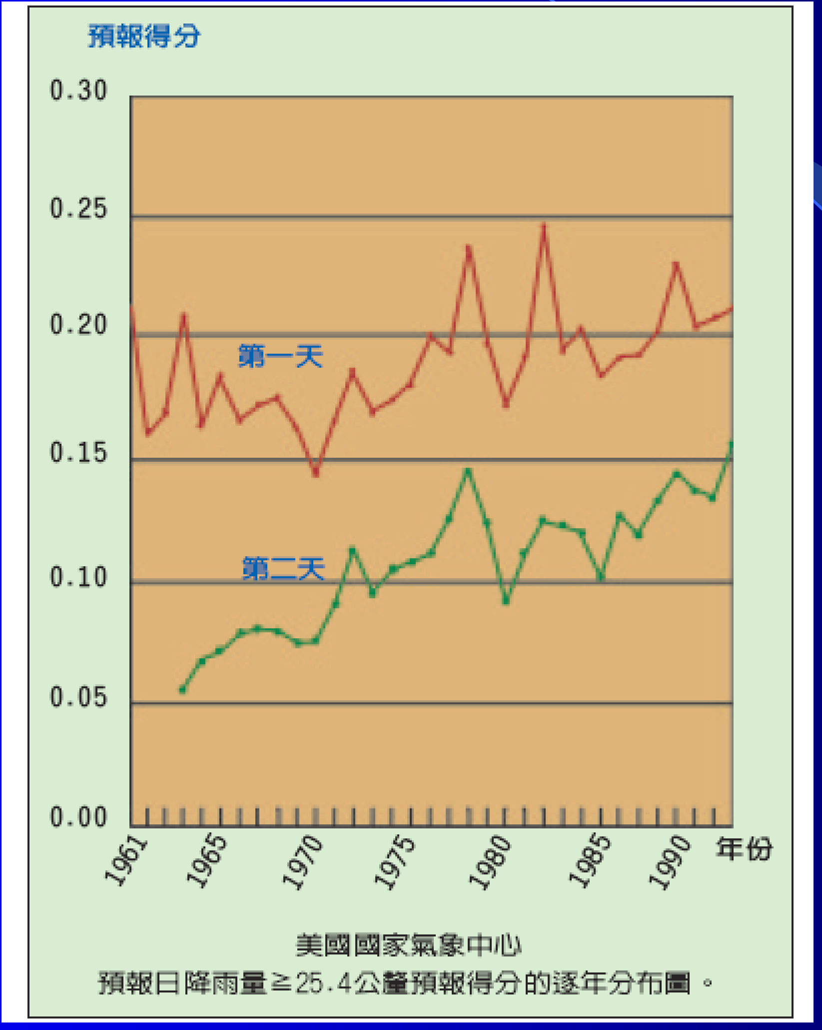
定量降水預報

Threat Score

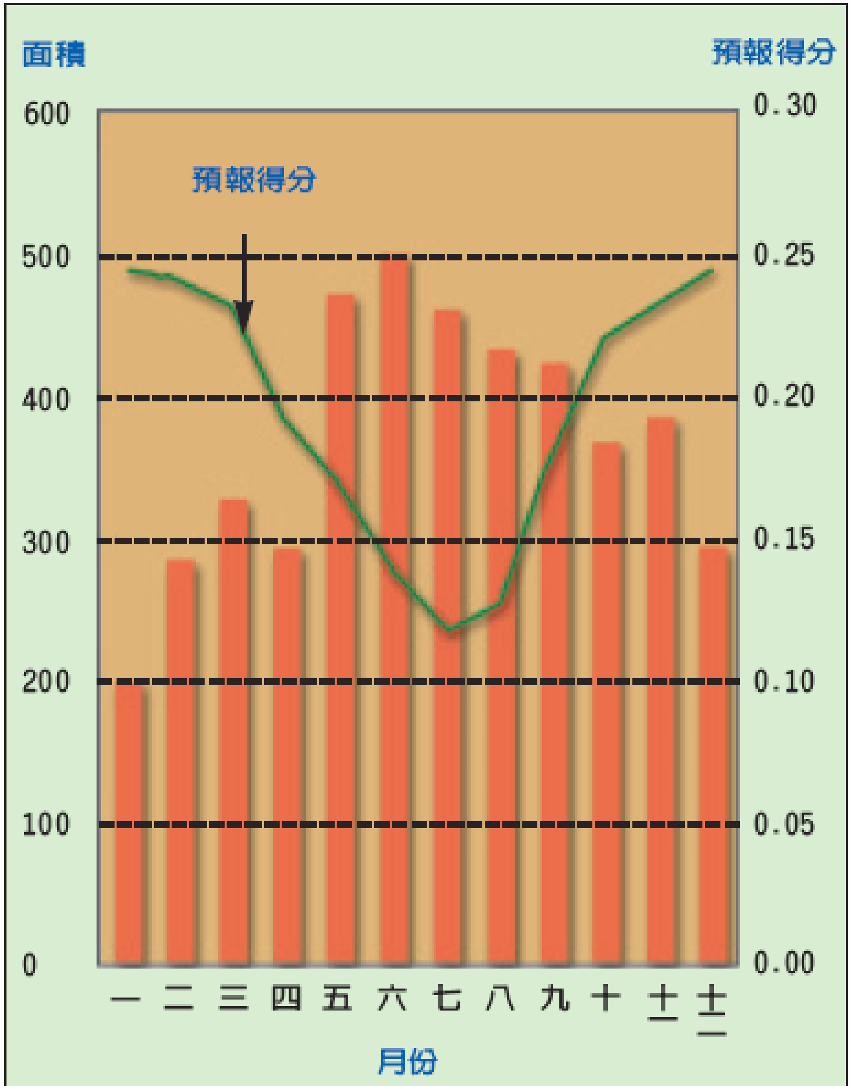


(陳泰然 2003)

定量降水預報

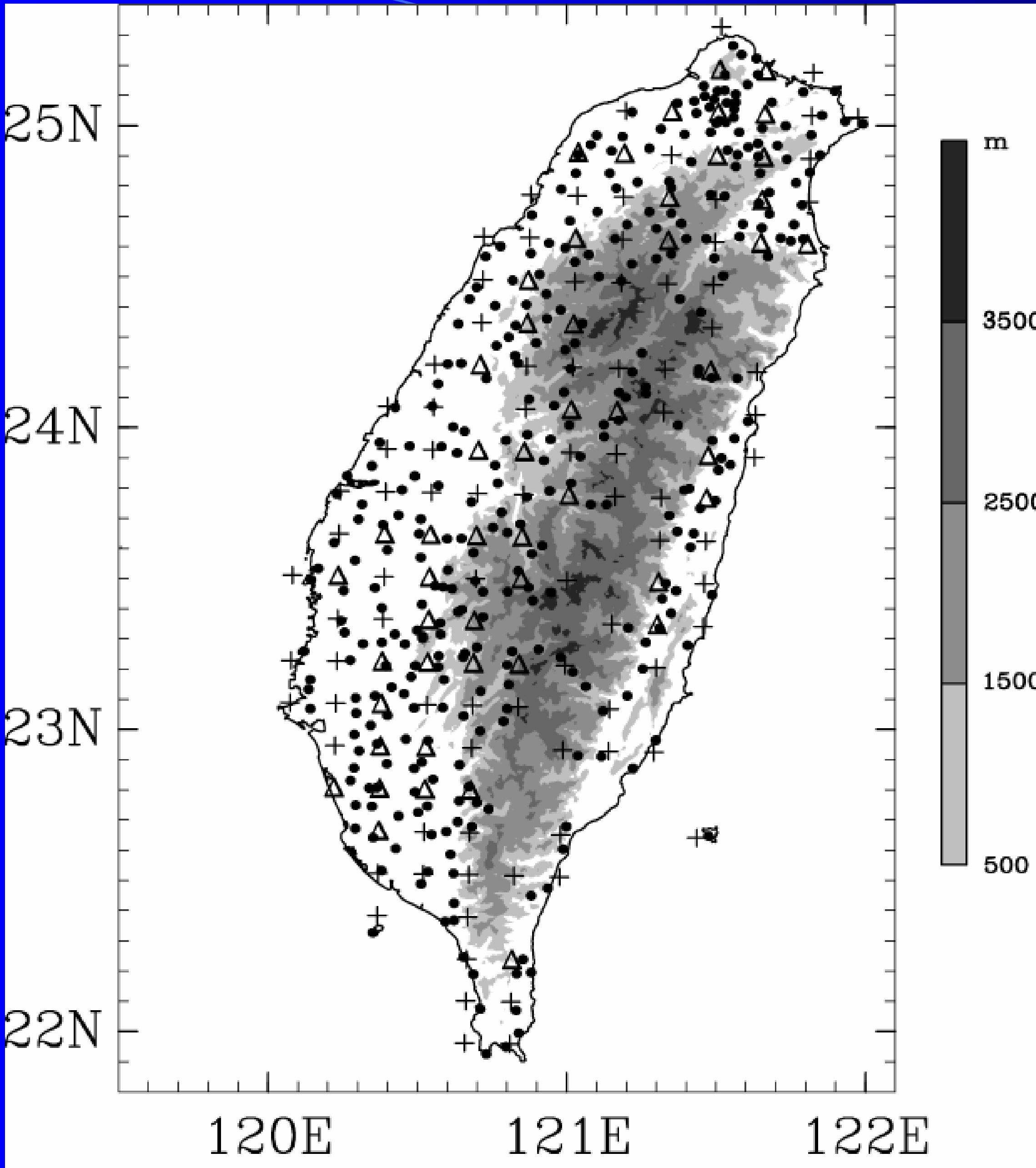


(陳泰然 2003; Adapted from Olson et al. 1995)



每個月平均的「預報得分」與「日雨量≧1.0英寸所含蓋的面積」兩者間的相關性，由上面分布圖顯示，暖季降雨比冷季多，但預報得分較小。簡單地說，雨量愈多，預報得分反而愈低。

(陳泰然 2003; Adapted from Olson et al. 1995)



- Raingauge (dot): 343 points
- MM5 grid (cross)
- MM5 grid for verification (triangle)

Rainfall Contingency Table

Observed / Forecasted	Rain	No Rain
Rain	A	B
No Rain	C	D

Note: N is the total number of events (A+B+C+D)

Evaluation Scores

Based on A, B, C, D in the contingency table, several forecast evaluation scores can be defines as:

BS (Bias Score) = (A+B)/(A+C)

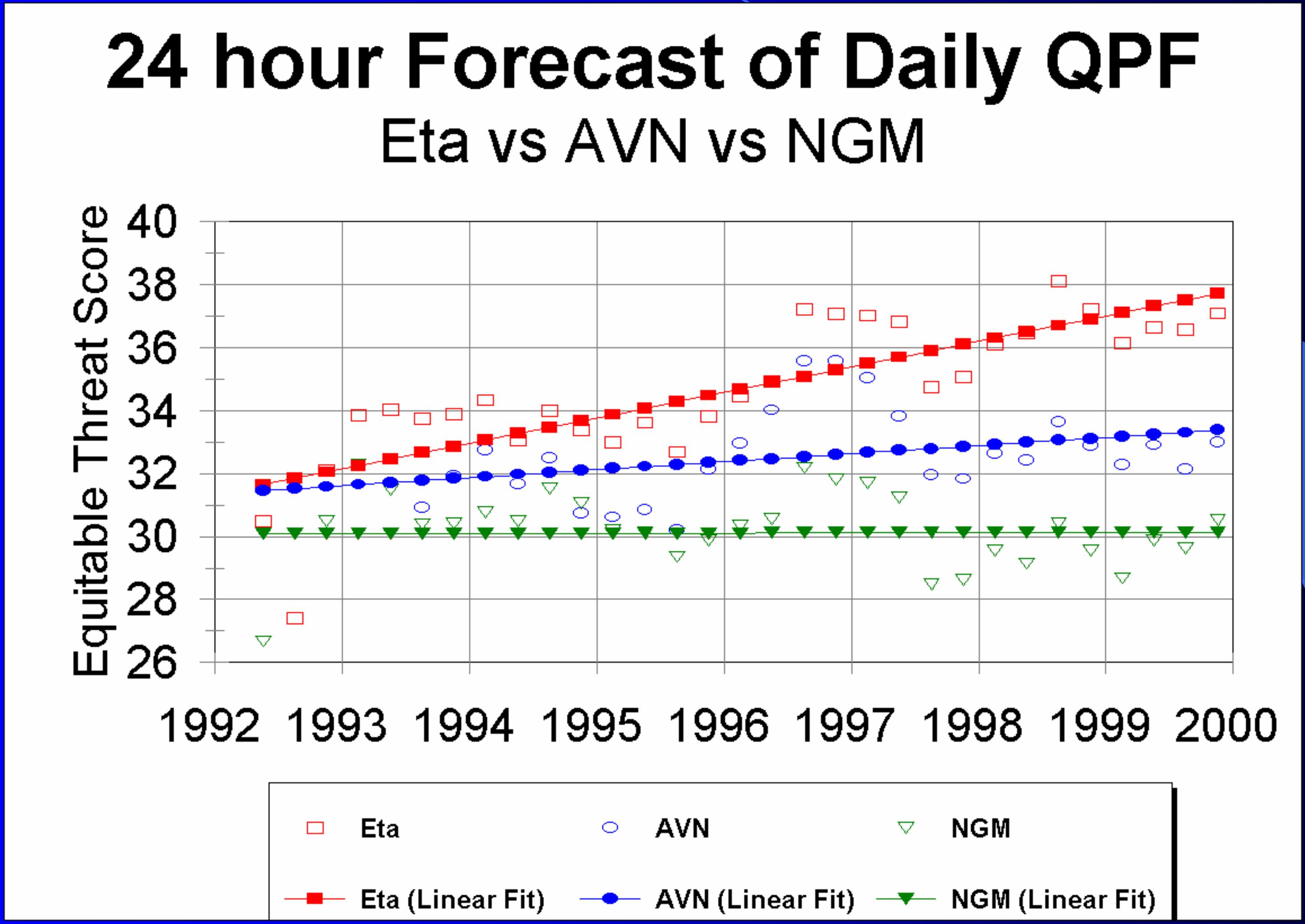
ETS (Equitable Threat Score) = (A-E)/(A+B+C-E)

E (Random Guess) = (A+B)*(A+C)/N

TS (Threat Score) = A/(A+B+C)

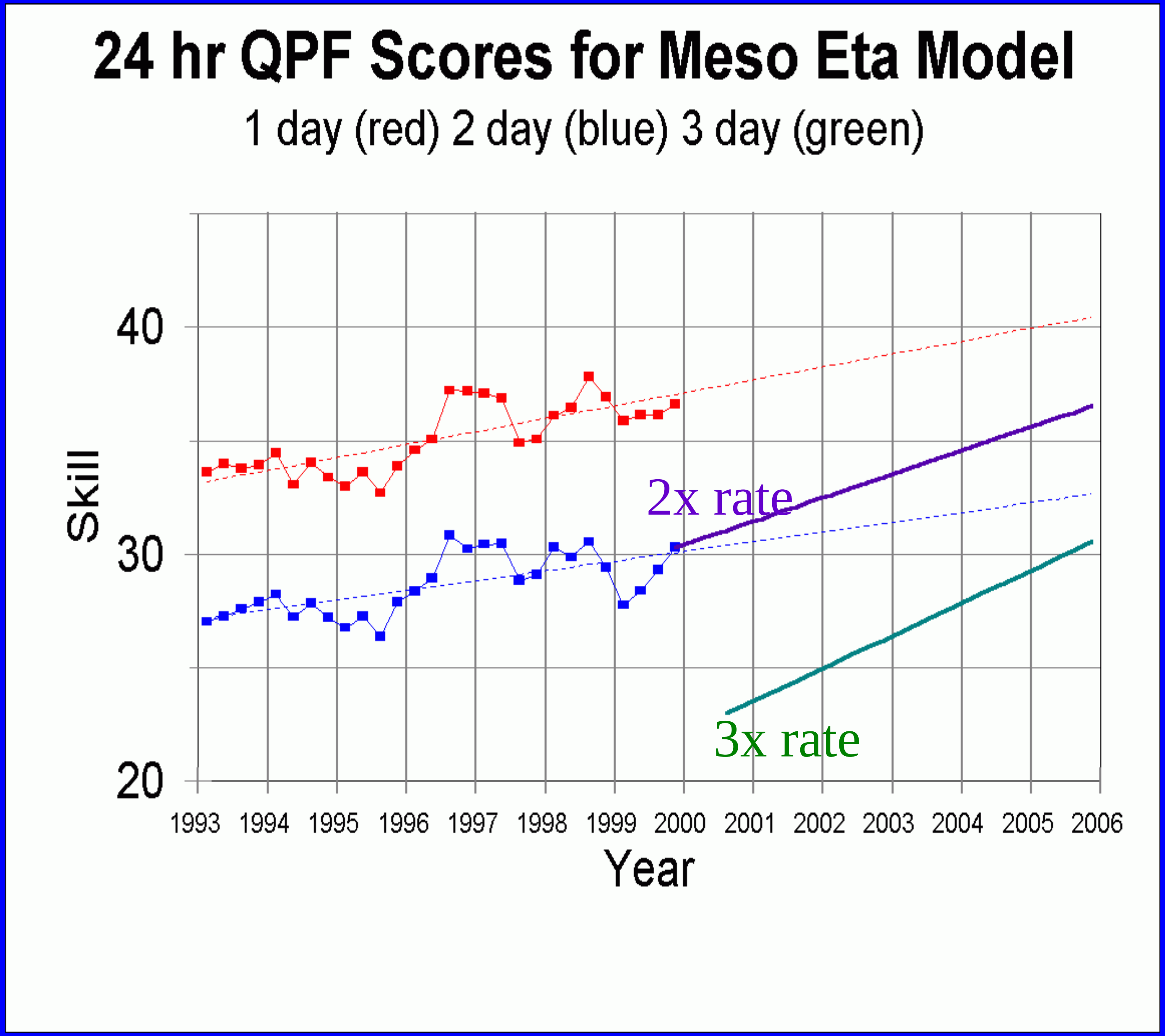
Note: N is the total number of events (A+B+C+D)

QPF Forecasts at NCEP:



(Figure courtesy of Geoff DiMego at NCEP, 2000)

ACCURACY



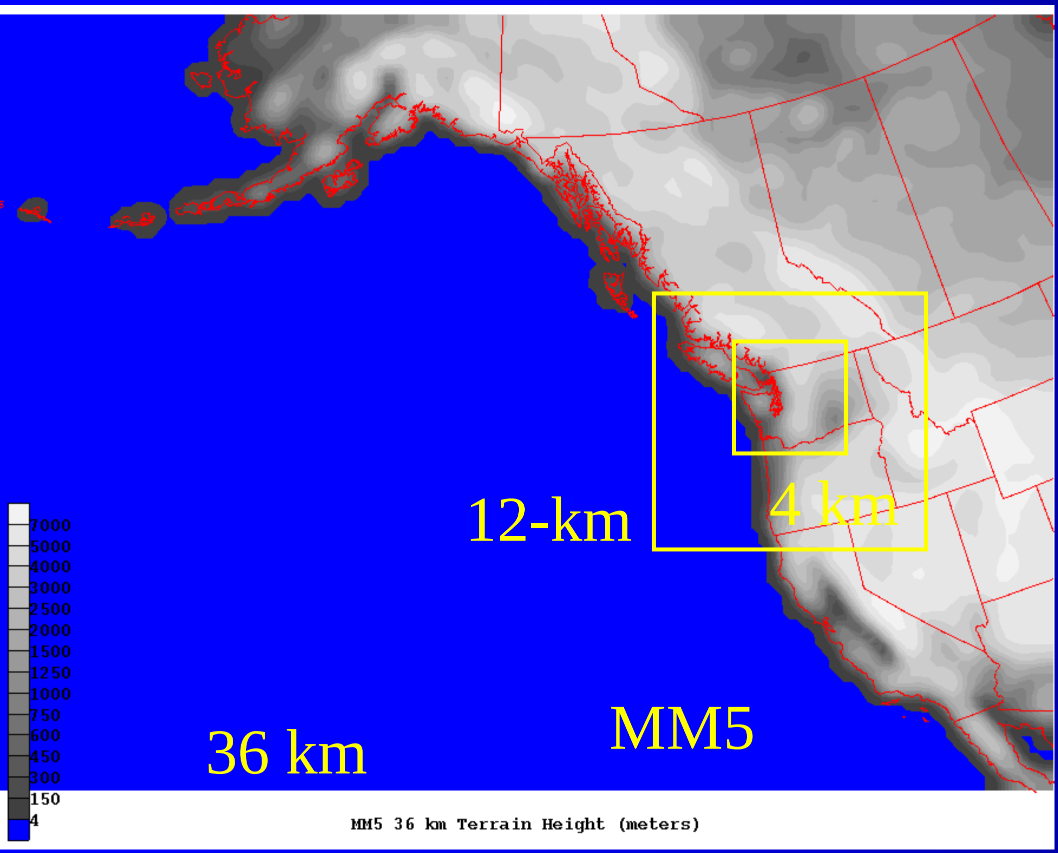
(Figure courtesy of Geoff DiMego at NCEP, 2000)

Faster Rate of Improvement Needed

- NCEP needs to **double** its improvement rate to make the quality of current 2 day QPF forecasts as good as current 1 day QPF forecasts by the end of FY2005.
- NCEP needs to **triple** its improvement rate to make the expected quality of soon-to-be-started 3 day QPF forecasts as good as current 2 day QPF forecasts by end of FY2005.
- NCEP's existing resources are not sufficient to increase the rate of improvement needed to achieve these goals

(Slide courtesy of Geoff DiMego at NCEP, 2000)

U. Washington Real-time System



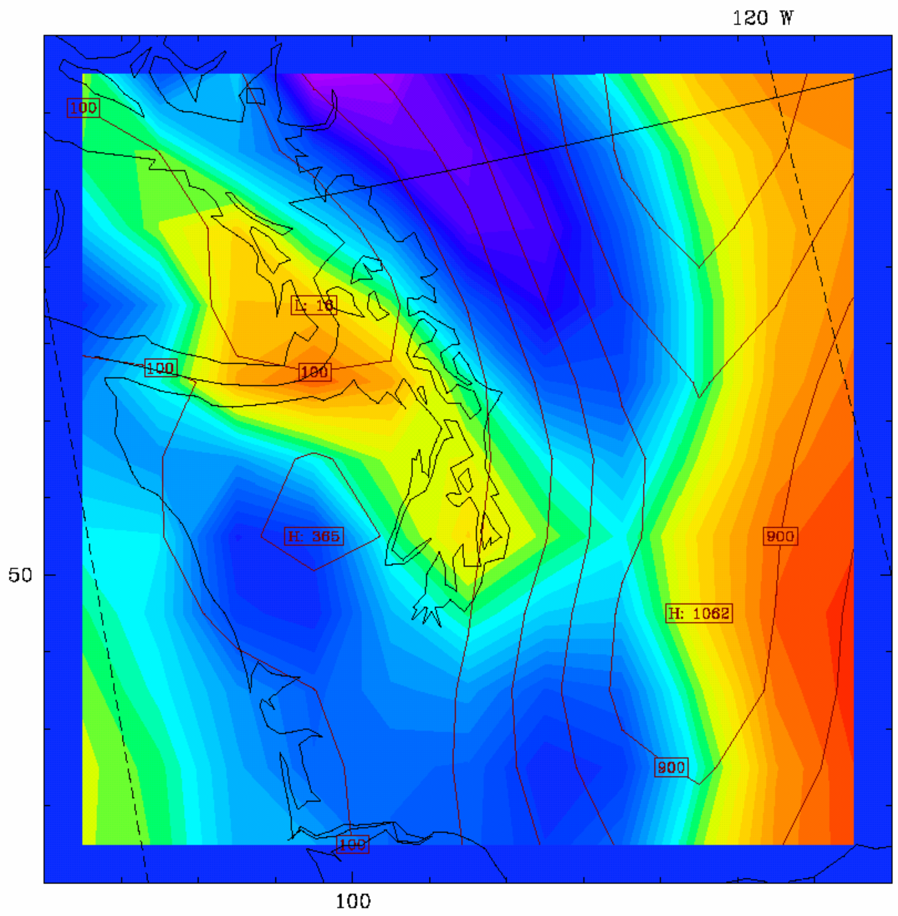
- 1995: One domain MM5 at 27 km (on a single processor DEC workstation).
- 1996: Two domains at 36/12 km (on 14-CPU SUN ES-4000).
- 1997: Three domains at 36/12/4 km (processors upgrade).
- 1999: Enlarge 4-km domain + 4 ensemble members (addition of DEC ES-40)
- 2000: Enlarge 4-km domain + 5 ensemble members (upgrade to DEC ES-6500).

(Slide courtesy of Cliff Mass, U.W.)

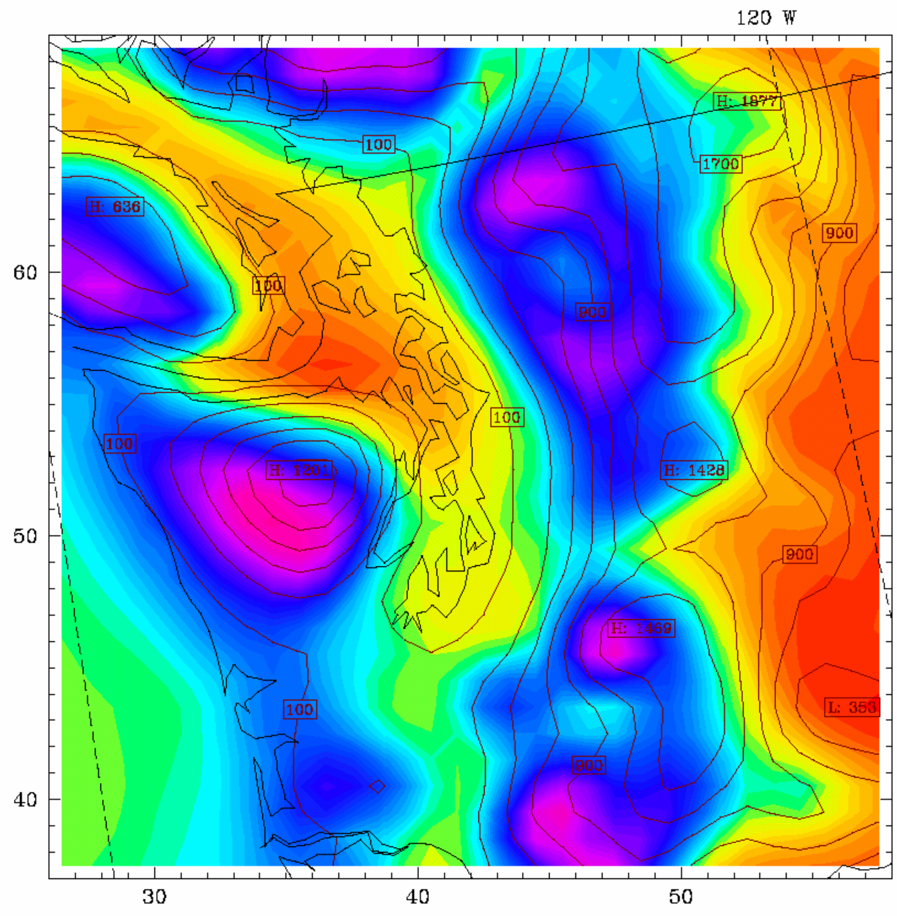
Effects of Resolution

Precipitation from two cold seasons

36-km grid



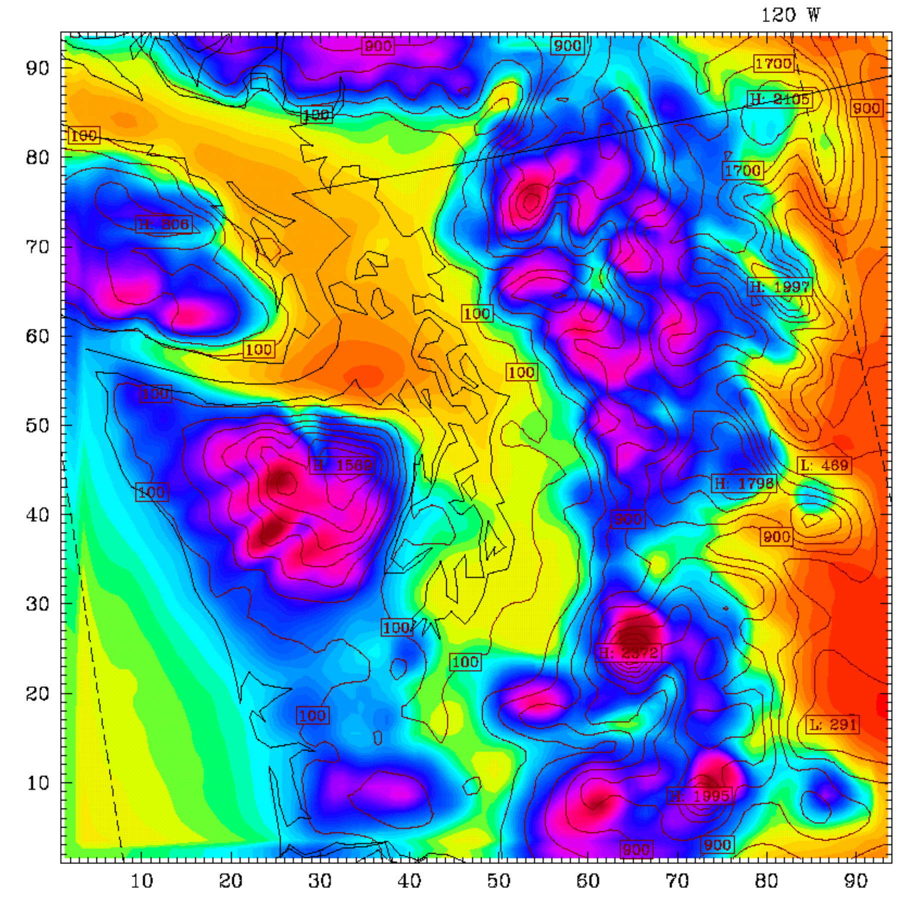
12-km grid



(Slide courtesy of Cliff Mass, U.W.)

Detailed Rainfall Distribution

4-km grid



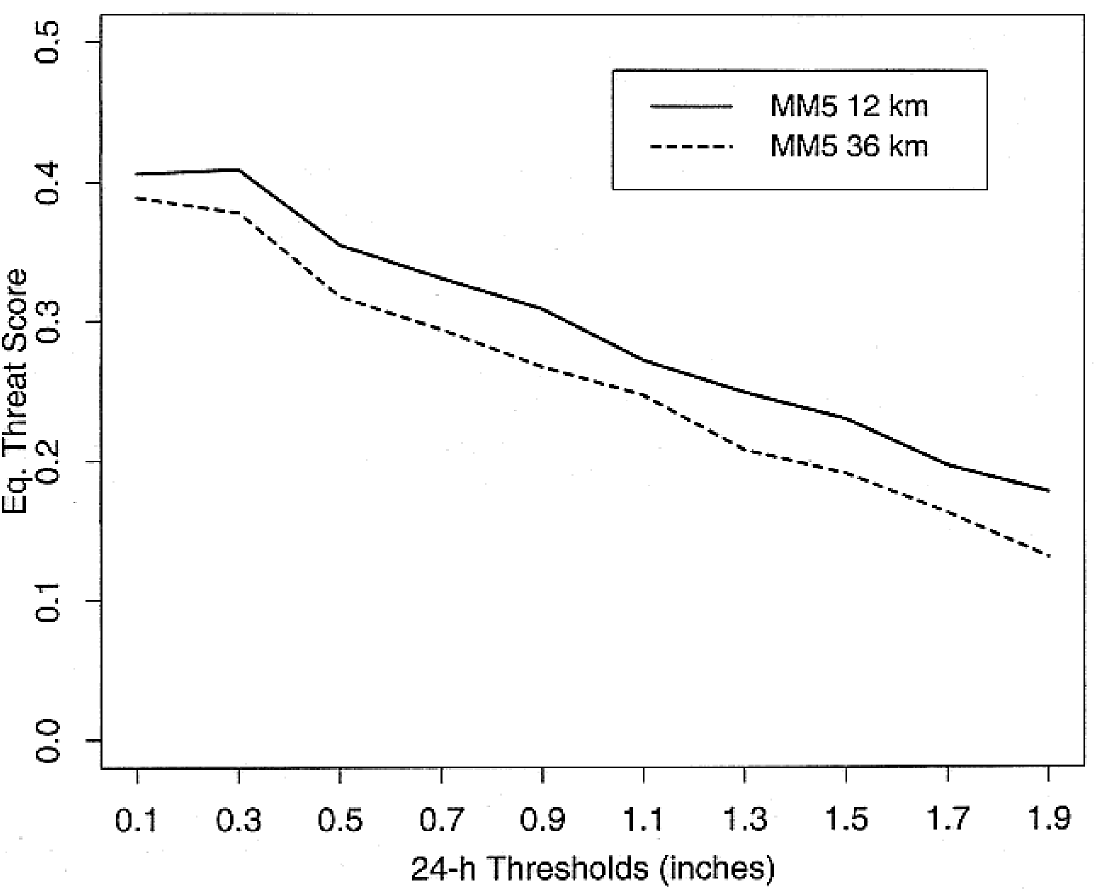
Precipitation from two cold seasons:
Oct 97 – Mar 98
Oct 98 – Mar 99

(Slide courtesy of Cliff Mass, U.W.)

Cold-season QPF in NW U.S.

Eq. Threat Scores (12-36h)

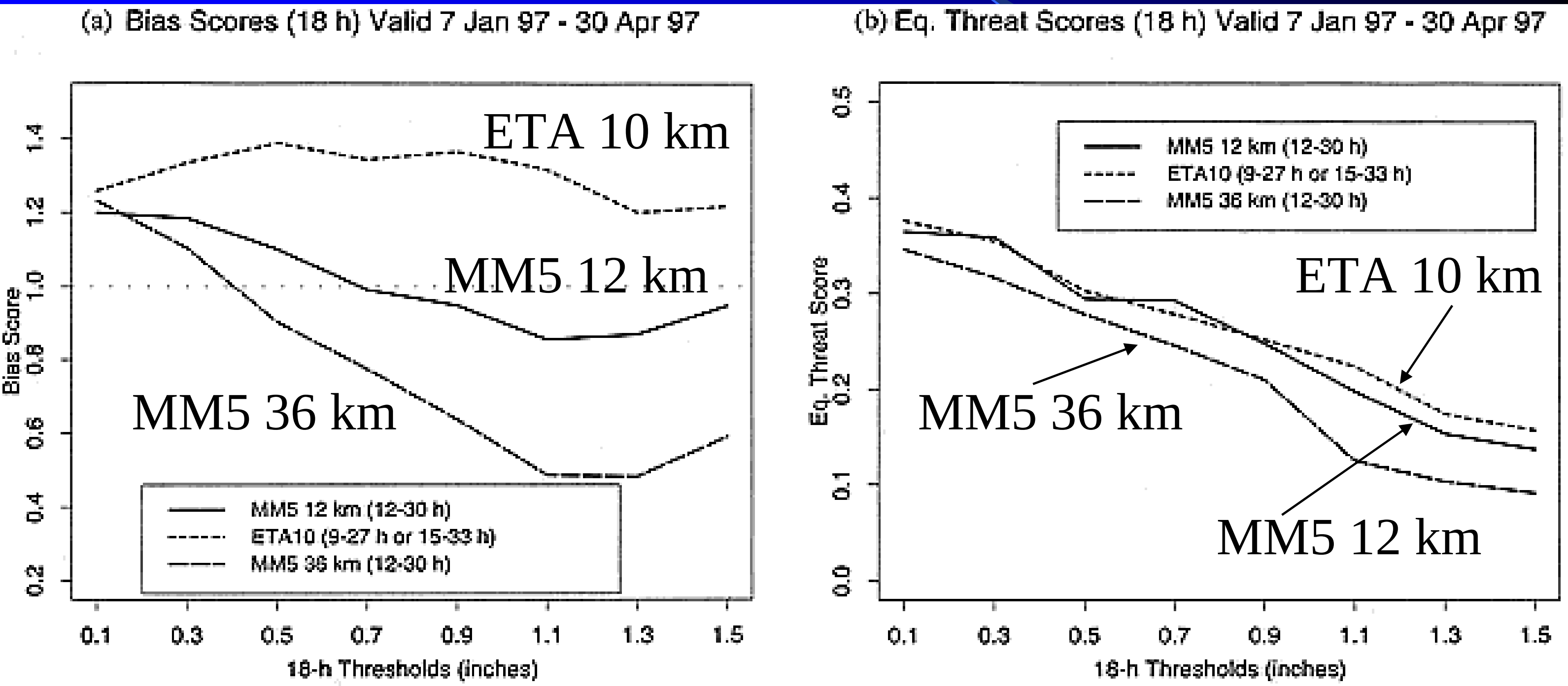
Valid 9 Dec 96 – 30 Apr 97



- Equitable threat scores vs. precipitation threshold (inches) calculated for the 12-36-h forecast period for the 36-km (dashed) and 12-km (solid) domains from 9 Dec 1996 through 30 April 1997.

From Colle et al. (1999)

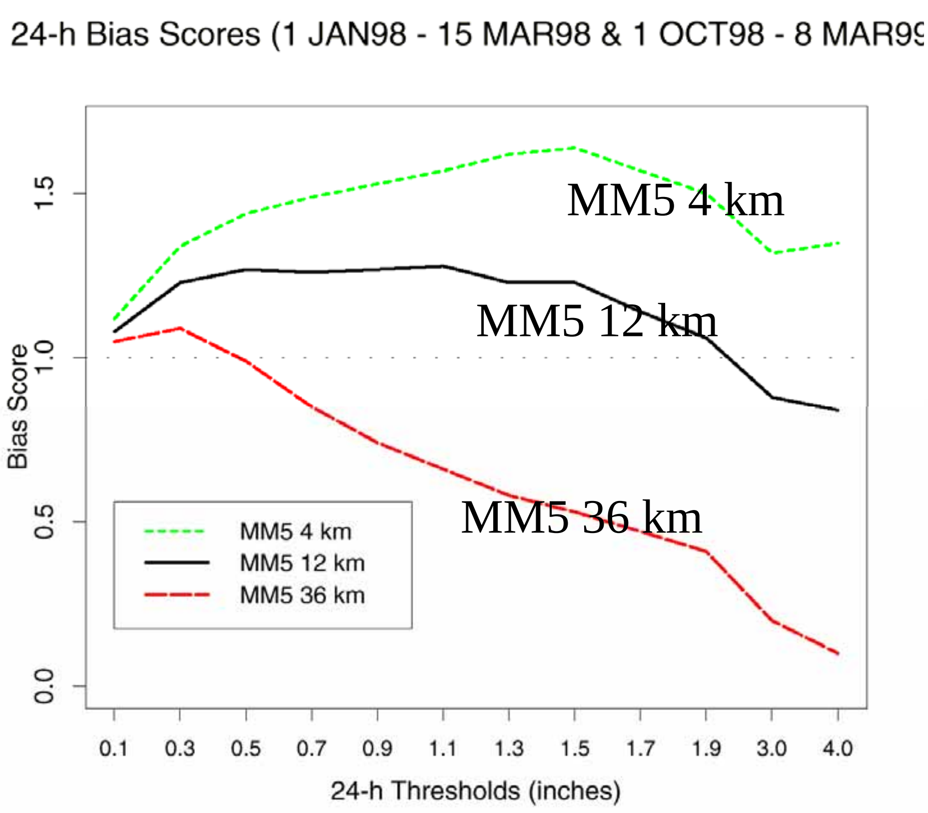
Comparison of QPF predictions

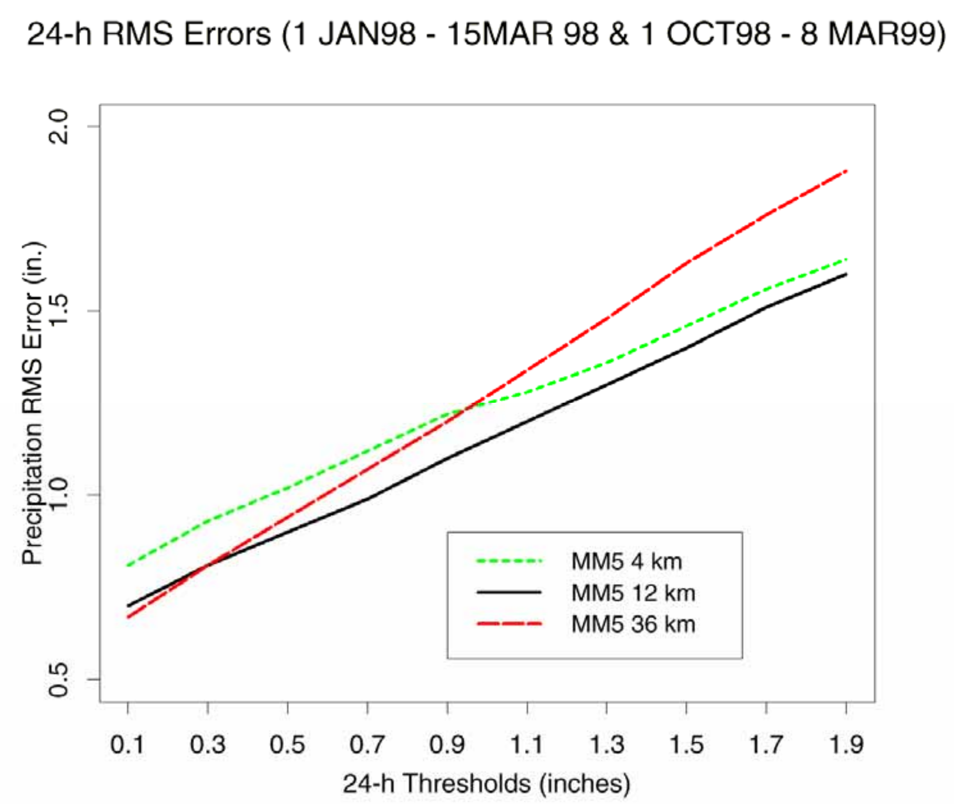


From Colle et al. (1999)

4-km model does not produce better forecast than the 12-km model, except for high precipitation thresholds.

The model total rainfall amount increases with resolution.

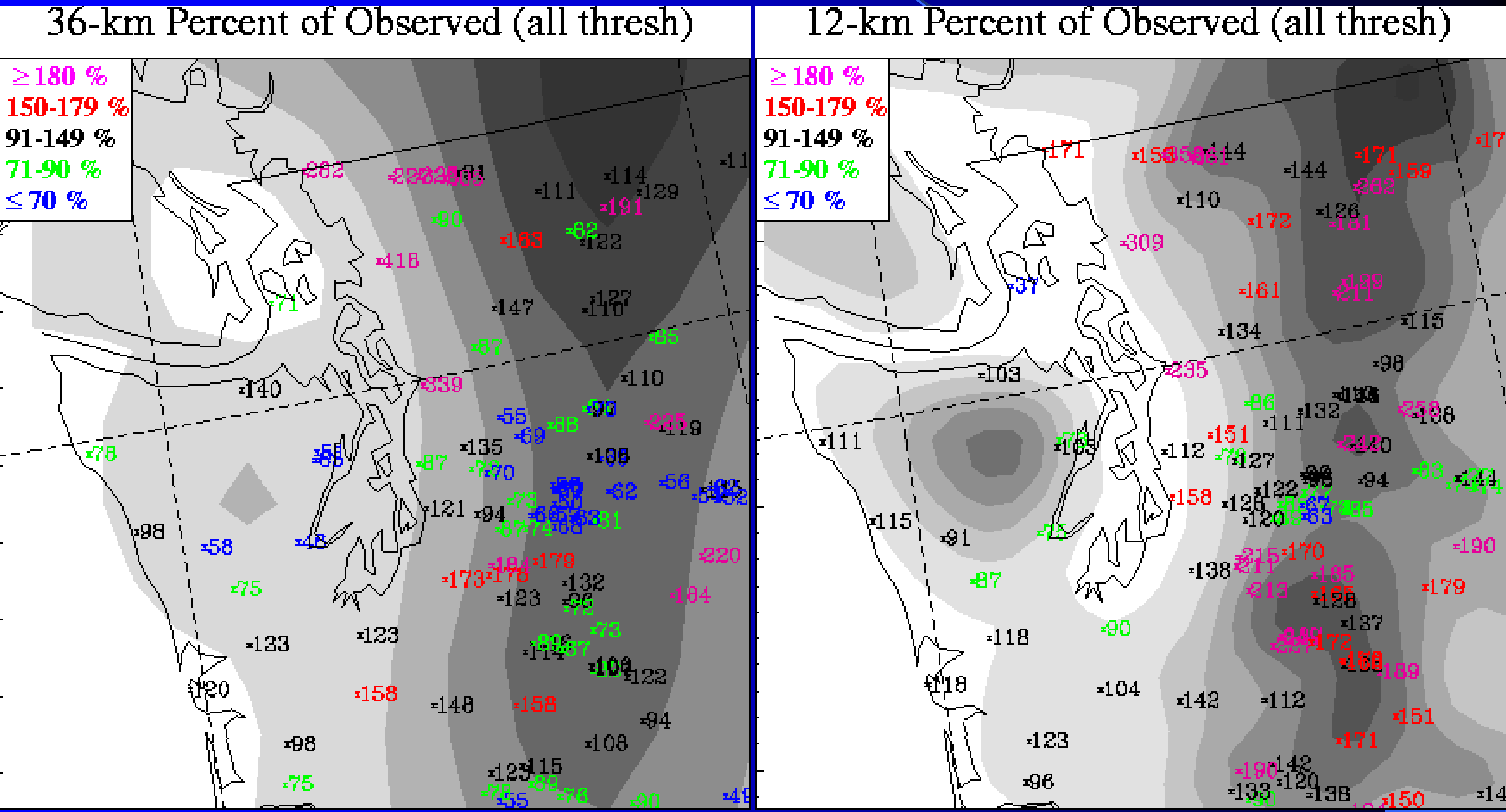




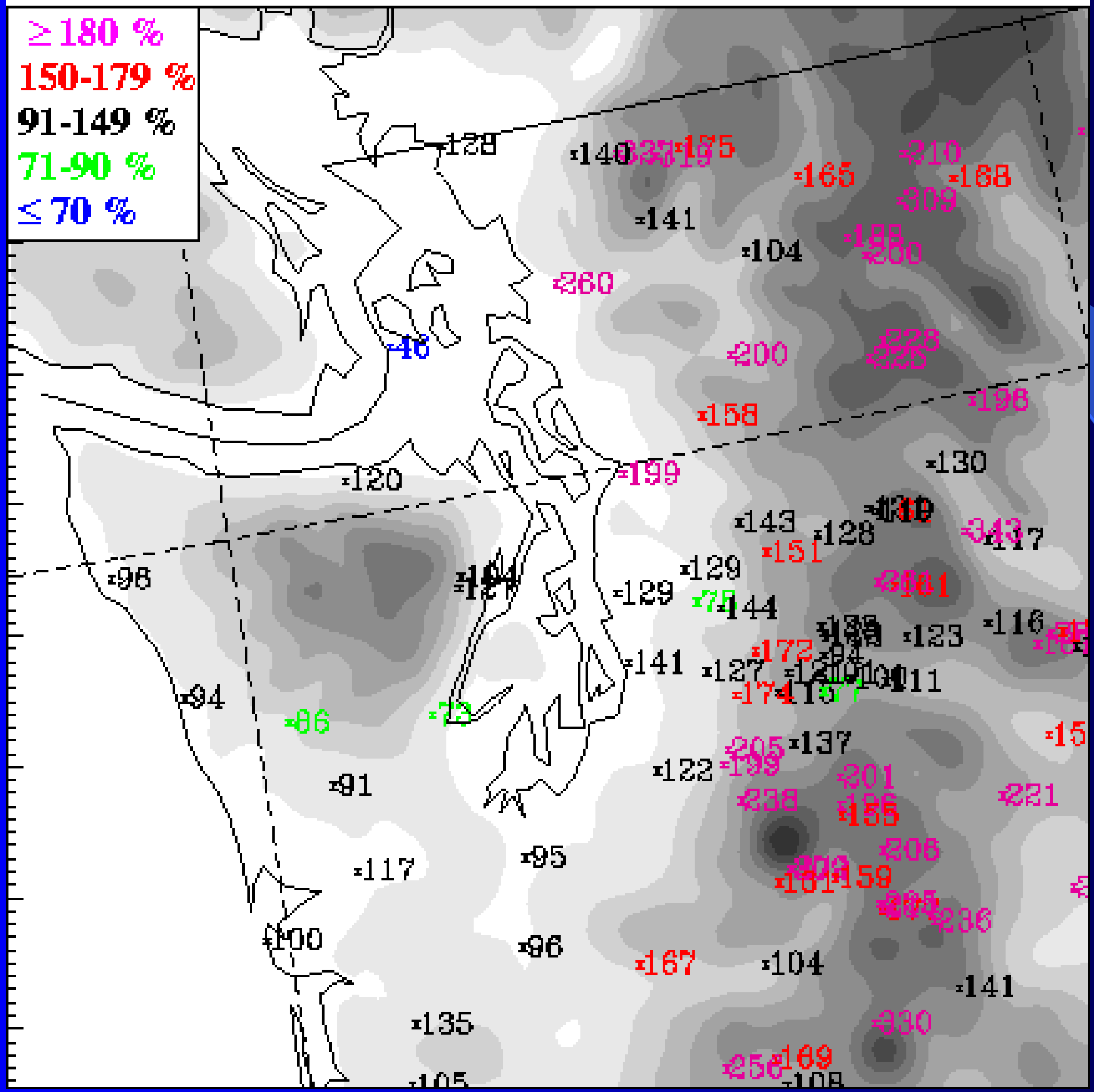
From Colle et al. (2000)

Excessive rainfall on the windward side, insufficient rainfall on the lee side.

Under prediction for 36 km, and over prediction for 4 km.



4-km Percent of Observed (all thresh)



Colle et al. (2000)

Sensitivity to microphysics schemes

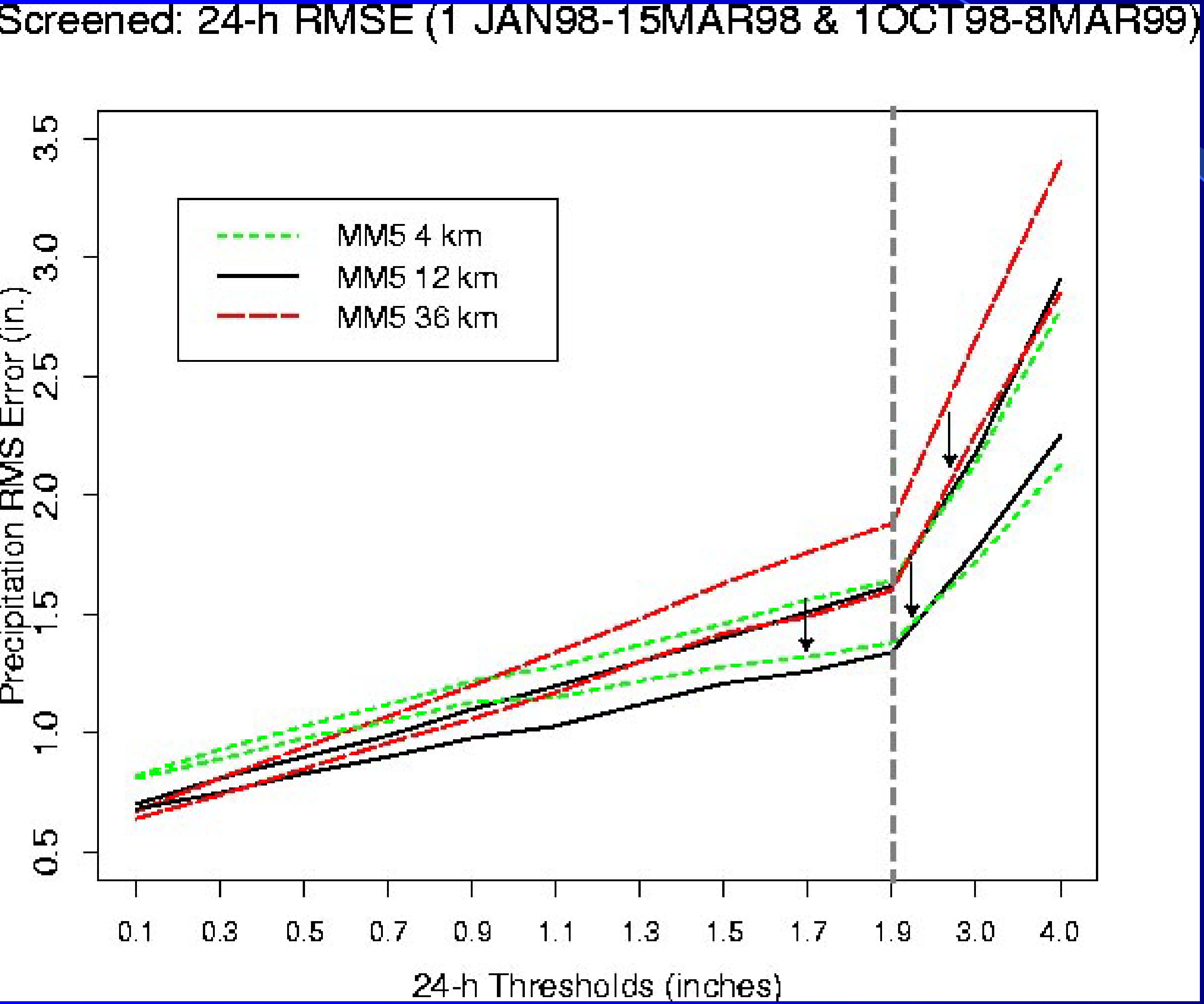
4 km RMS Error for 24 h (8-32) forecast of Feb’96 flood

Red: largest error, Blue: smallest error

Threshold (mm)	Warm Rain (V 2.3)	Simple Ice (V 2.3)	Schultz (V 2.12)	Reis1 (V2.3)	Reis2 (V2.12)	Reis2 (V2.3)
< 20	10.6	14.6	14.5	16.7	15.4	17.9
20-60	28.1	24.8	38.6	21.8	23.6	19.2
60-100	51.4	35.6	56.4	30.8	36.7	36.4
100-130	52.3	44.2	57.9	44.2	51.4	45.9
> 130	66.4	65.9	79.0	66.3	78.6	66.8
All	41.1	35.0	48.3	33.6	38.9	35.0

From Colle et al. (2000)

Influence of Synoptic-scale prediction



Model precipitation forecast skill increases if poor synoptic scale forecast cases are removed.

➔

Quality of mesoscale prediction is affected strongly by synoptic prediction.

Colle et al. (2000)

To reduce uncertainties in initial condition and physics parameterization

→

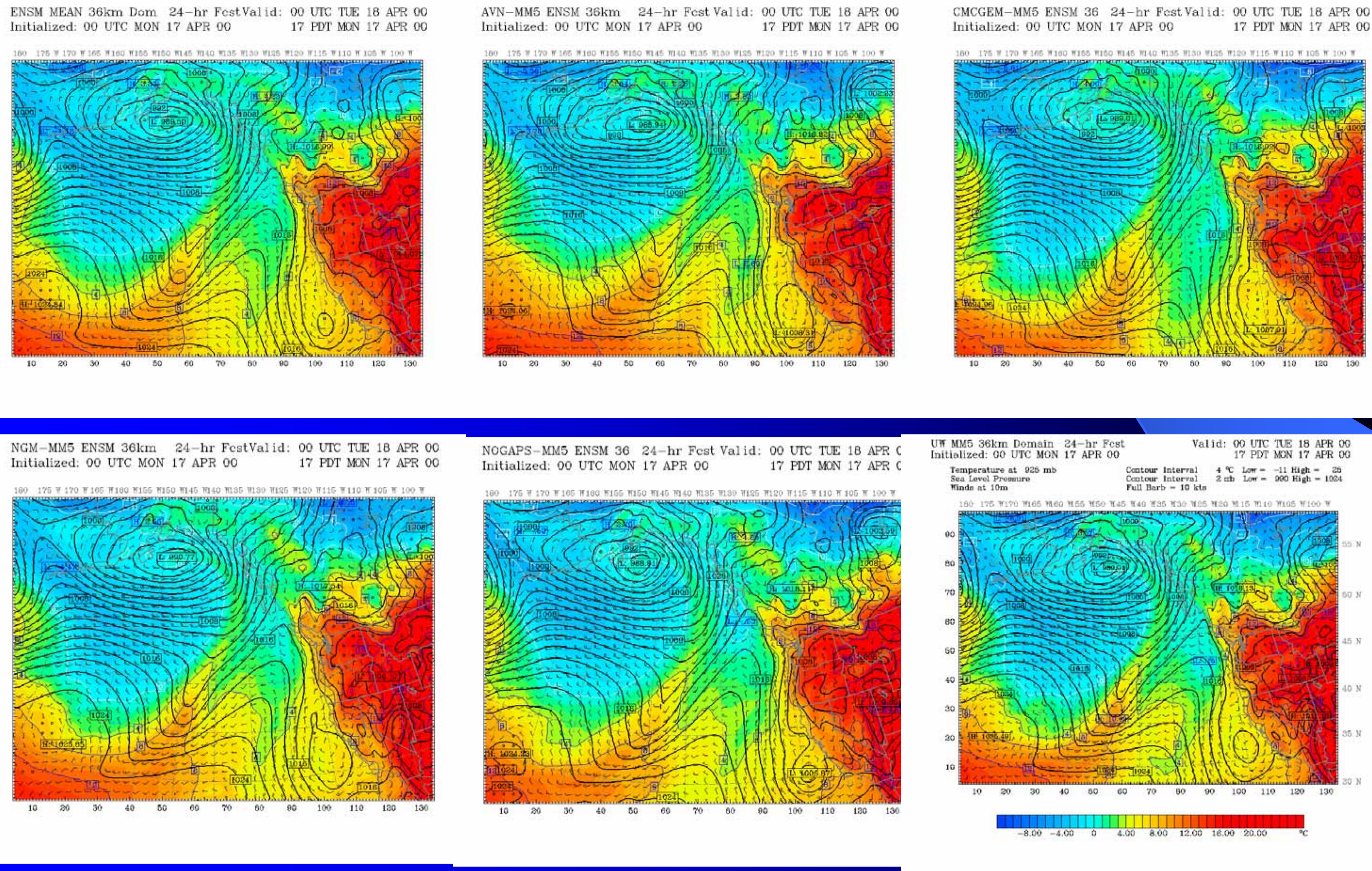
Ensemble Forecasting!

UW Mesoscale Ensemble System

- MM5 runs at 36 and 12 km resolution for 48 h 0000 UTC cycle only.
- Initializations and lateral boundary conditions from five different operational systems: Eta, NGM, NOGAPS, Canadian GEM, AVN.
- There is often a substantial variance among the above initializations. This variance is a measure of uncertainty in the operational analyses /initializations.
- Each ensemble forecast and ensemble mean are verified against regional mesoscale database.

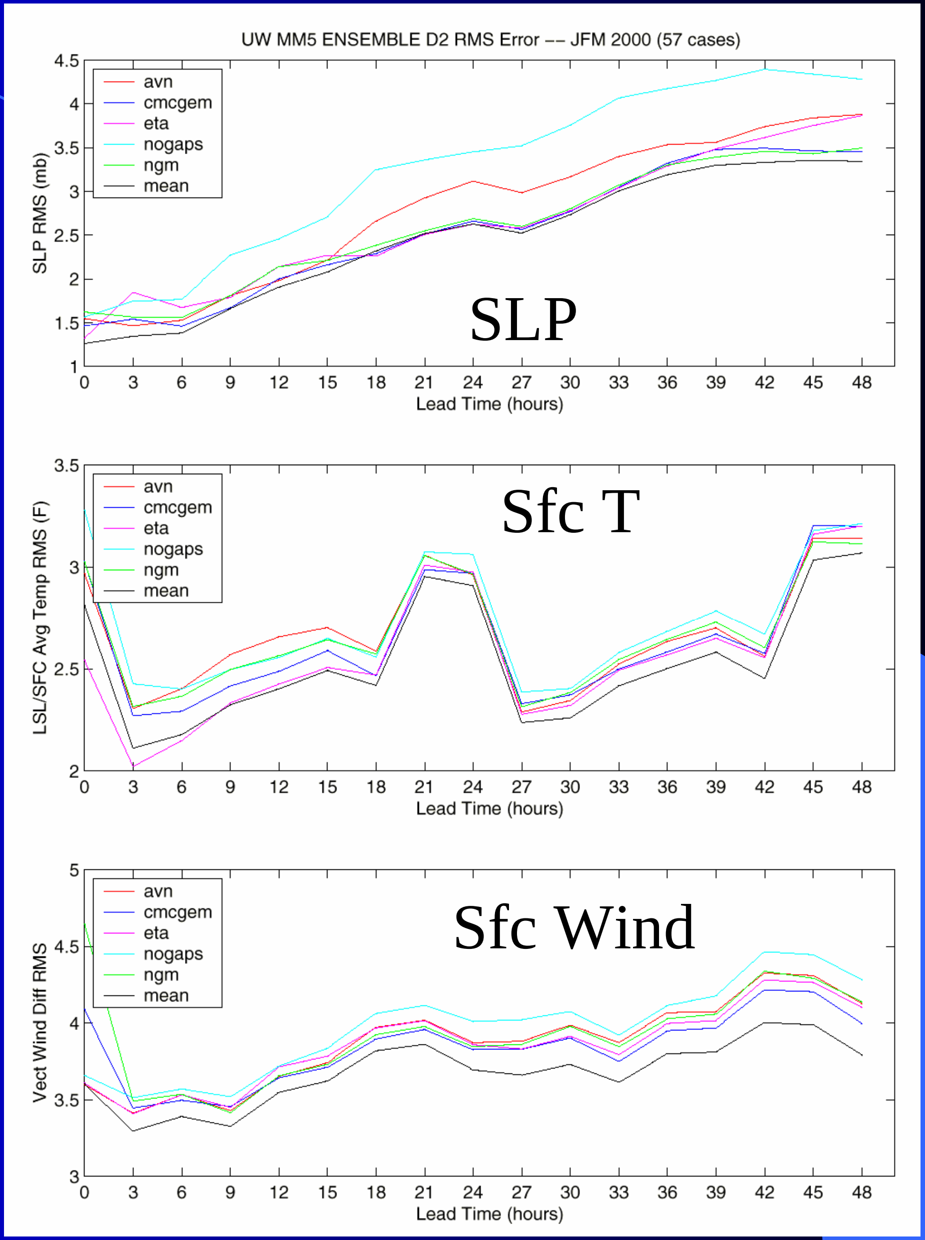
From Prof. C. Mass, UW

24-h FCST from 0000 UTC 17 April 2000



Verification

- Verification of ensemble forecasting over 57 cases, using mesoscale observations over the Pacific N.W.
- Ensemble mean provides the best overall prediction.



Slide provided by Cliff Mass (U. of Washington)

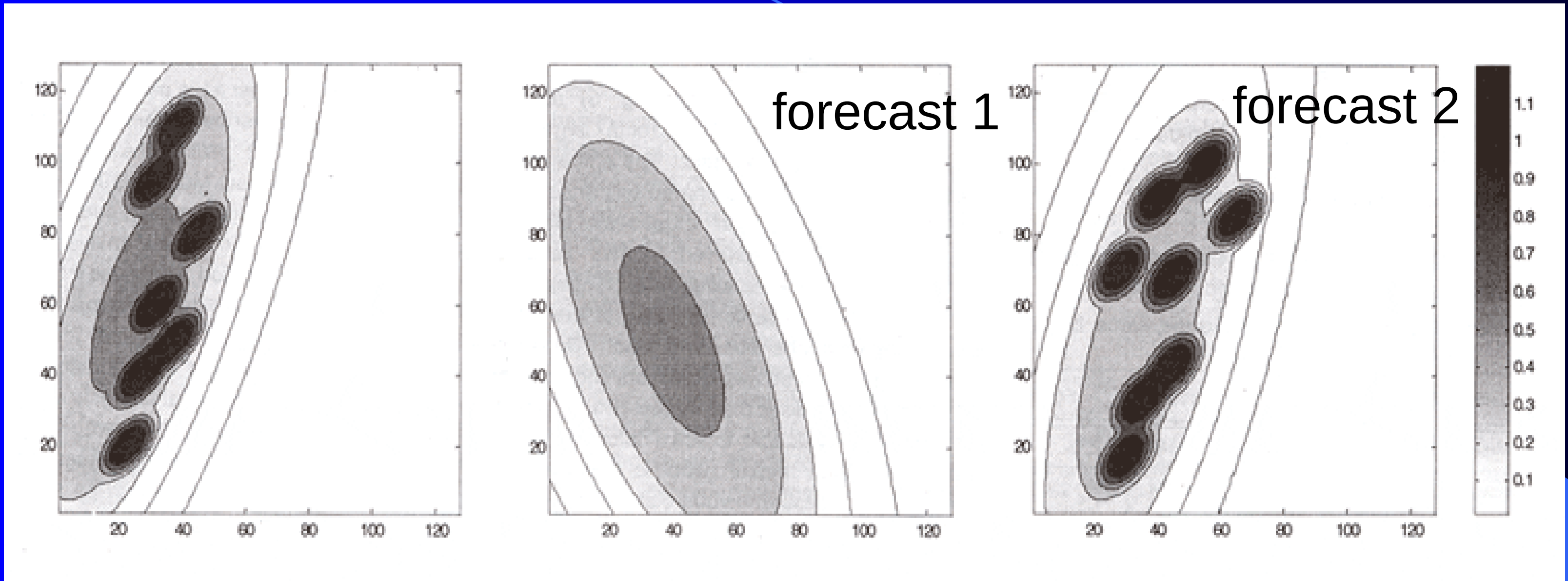
Lessons learned from NWP@UW:

- High-resolution models provide considerable skill in predicting local circulation and mesocale rainfall distribution.
- The quality of mesoscale prediction is strongly affected by the quality of the synoptic-scale forecast.
- Based on the verification results from U.W. system, high-resolution models tend to over-predict cold season precipitation.
  - High resolution model does NOT necessarily provide better forecast.
  - Model cloud microphysics require improvement.
- Ensemble forecasting offer promises to provide improved mesoscale prediction.
- Careful verification is needed to understand the promises and problems of mesoscale NWP.

Future directions for improving QPF:

- Continue to improve model physics and numerics:
  - Microphysics, PBL, land surface process, radiation, numerical schemes, … etc
- Better use of observations for model initialization:
  - 3DVAR/4DVAR development
  - Use of radar, satellite, and other remote sensing observations
- Ensemble forecasting:
  - Provide scientific basis for probability forecast
  - Provide an estimate of forecast reliability
  - Need apply to high resolution models
- Verification of mesoscale prediction
  - Attempt new verification methods
- Improve mesoscale observational data base

Problems with Traditional Verification Schemes

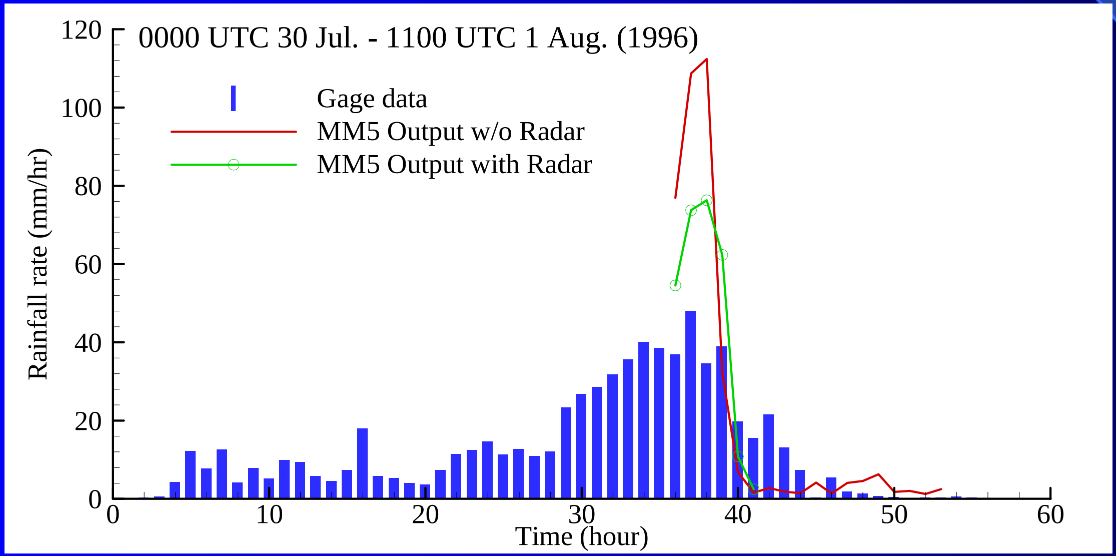


Verification measure	Forecast #1	Forecast #2
Mean absolute error	0.157	0.159
RMS error	0.254	0.309
Bias	0.98	0.98
Threat score	0.214	0.161
Equitable threat score	0.170	0.102

Issue: the obviously poorer forecast has better skill scores!

From Mike Baldwin NOAA/NSSL

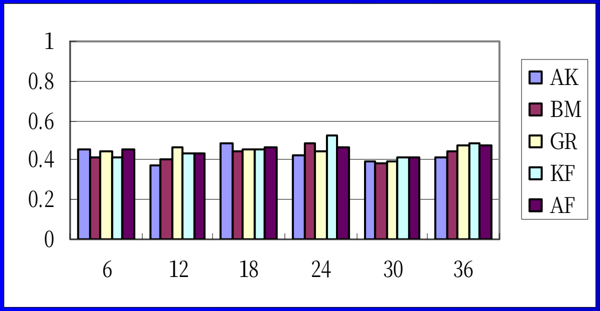
Impact of Radar Data Assimilation on QPF: A Case Study of Typhoon Herb (1996)



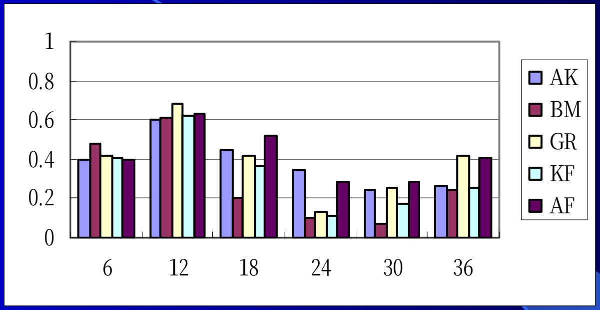
Application in Taiwan

Typical TS for Different Weather System in Taiwan

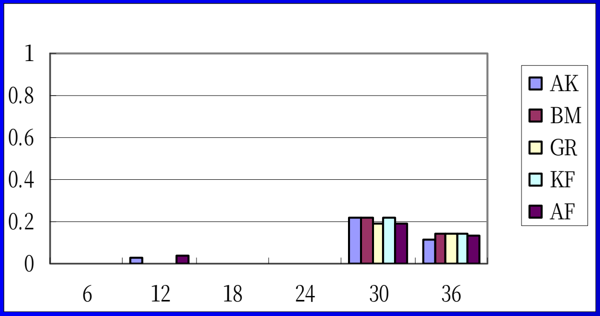
Winter cold-air outbreak



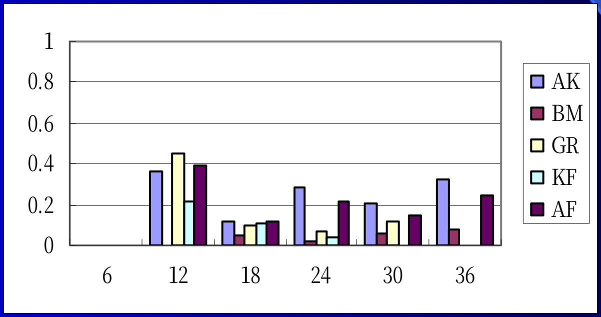
Autumn cold front



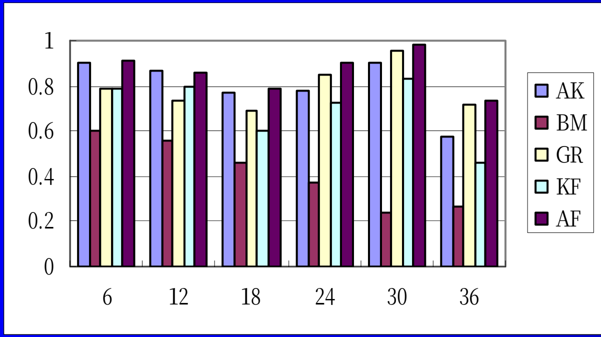
Spring rainfall



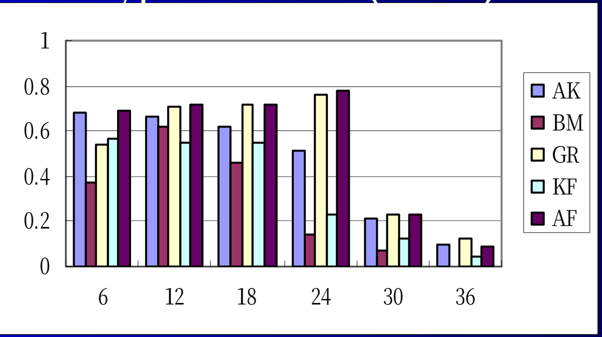
Summer thunderstorm



Mei-Yu front

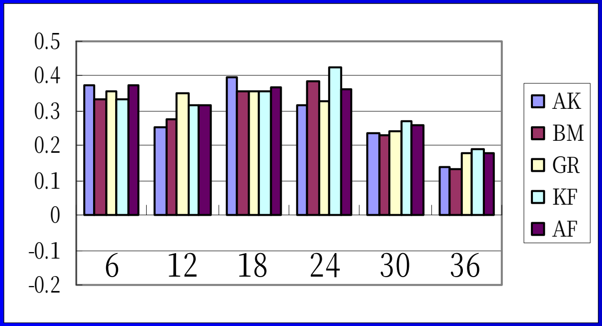


Typhoon Otto (1998)

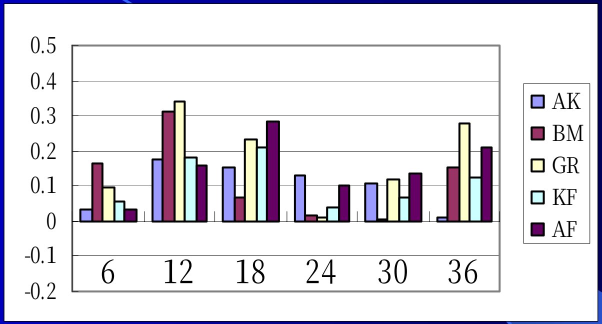


Typical ETS for Different Weather System in Taiwan

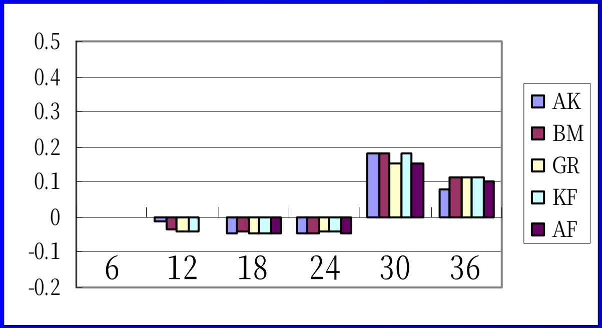
Winter cold-air outbreak



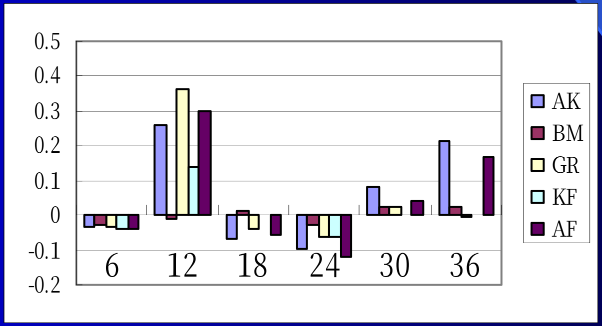
Autumn cold front



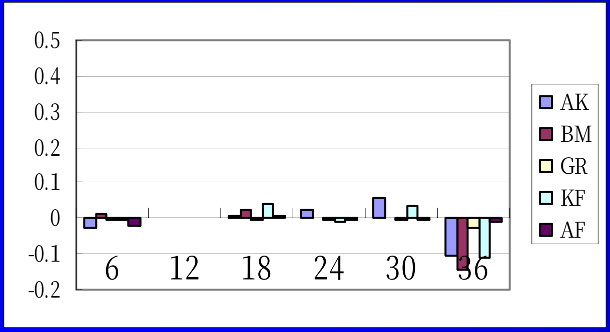
Spring rainfall



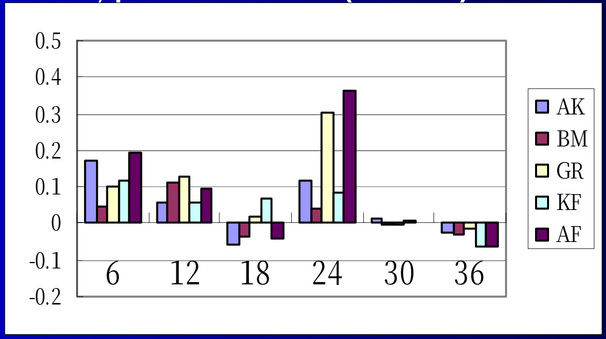
Summer thunderstorm



Mei-Yu front



Typhoon Otto (1998)



Ensemble Rainfall Forecast Experiment during the Mei-Yu Seasons (since 2000)

Participants:

Ming-Jen Yang (PCCU),

Ben J.-D. Jou (NTU) ,

Fang-Ching Chien (NTNU),

Pay-Liam Lin (NCU),

Jing-Shan Hong (CWB),

Jen-Hsin Teng (CWB),

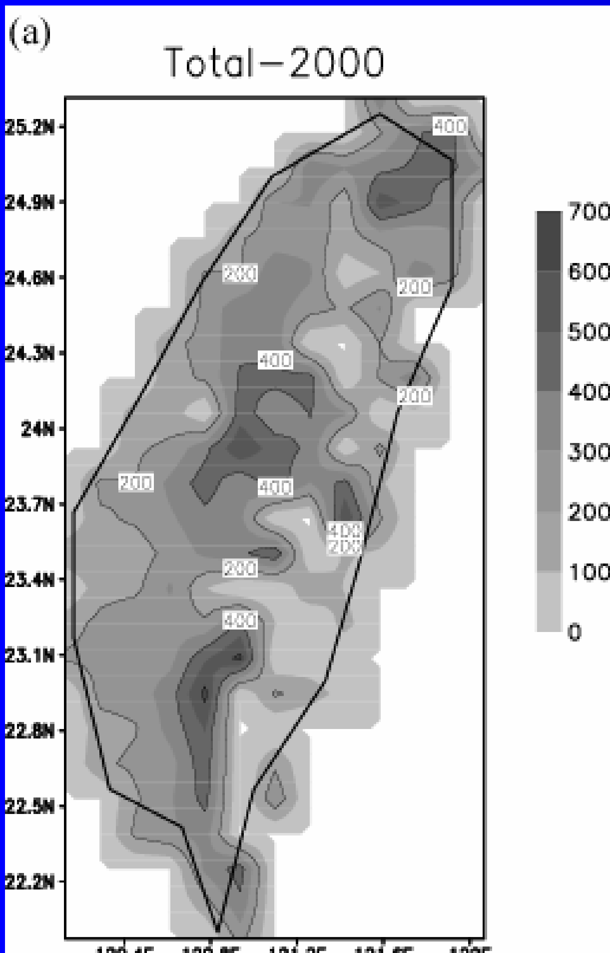
Huei-Chuan Lin (CAA)

Publications: Yang et al. (2004; JGR),
Chien and Jou (2004; WAF)
簡等(2003; 大氣科學)

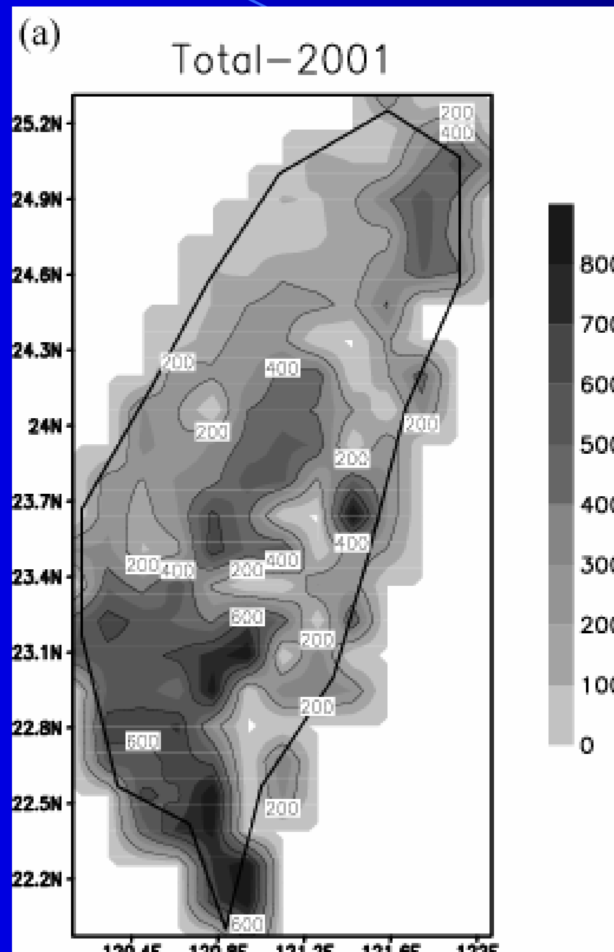
Precipitation Physics Combination of Ensemble Members

Member	Cumulus	Microphysics	Site
BR	Betts-Miller	Reisner 1	NCU
KS	Kain-Fritsch	Simple Ice	NTNU
KG	Kain-Fritsch	Goddard	PCCU
AR	Anthes-Kuo	Reisner 1	CWB
GR	Grell	Reisner 1	NTU
KR	Kain-Fritsch	Reisner 1	CAA

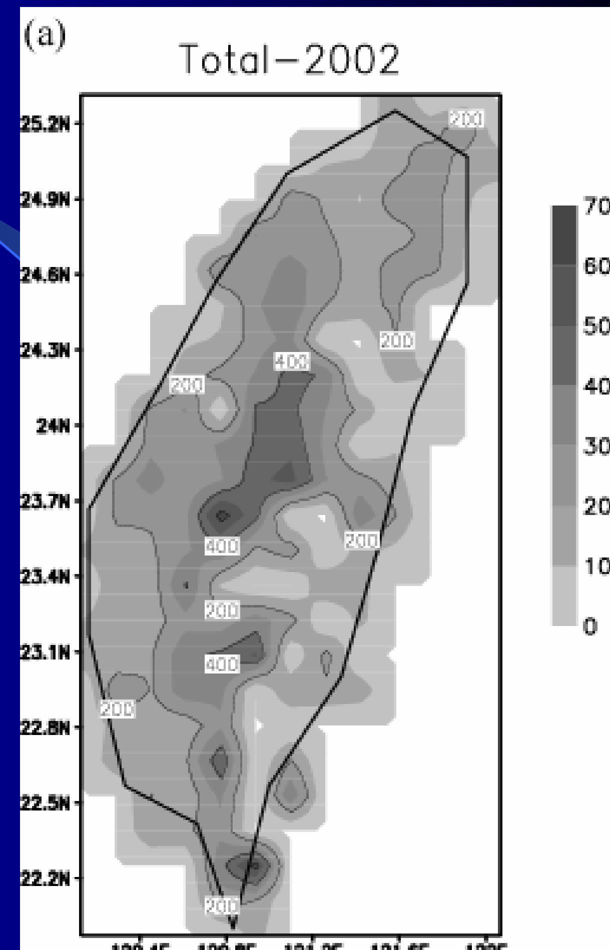
Rainfall Distribution during 2000~2002 Mei-Yu Seasons



2000

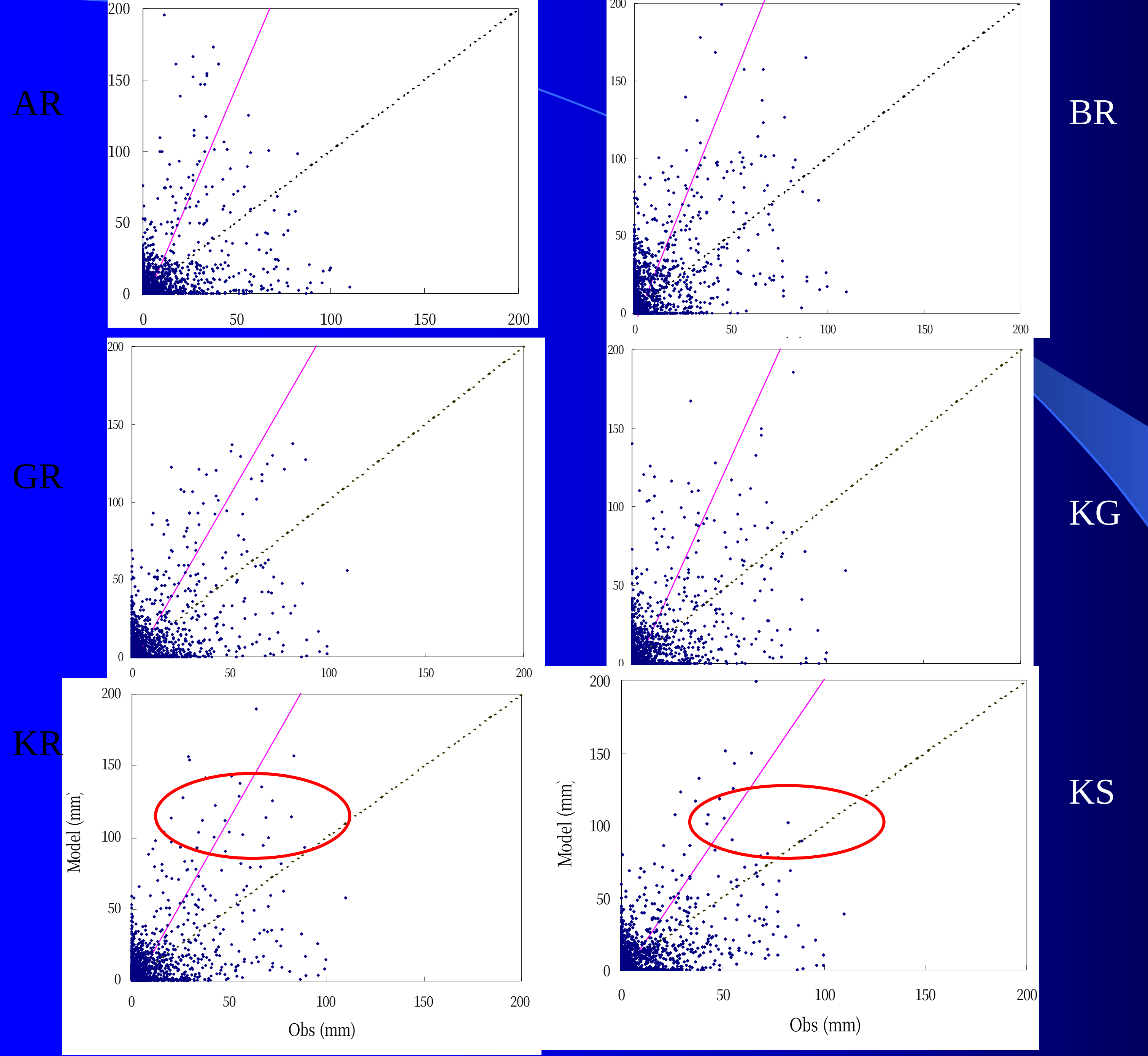


2001



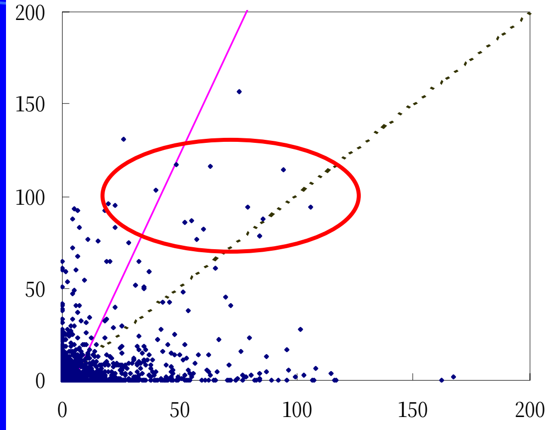
2002

Observed vs. Forecasted Rainfall Amount for the 12-24 h Forecast during the 2000 Mei-Yu Season

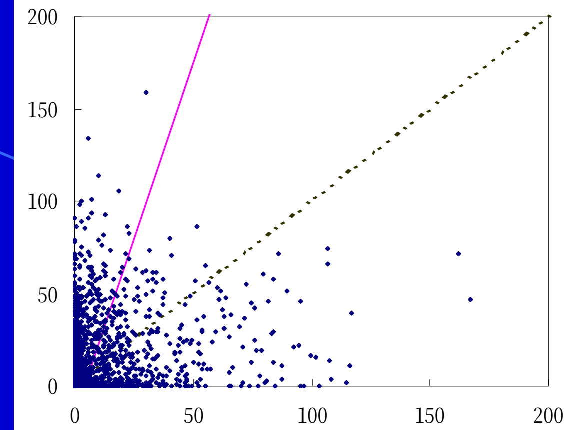


Observed vs. Forecasted Rainfall Amount for the 12-24 h Forecast during the 2001 Mei-Yu Season

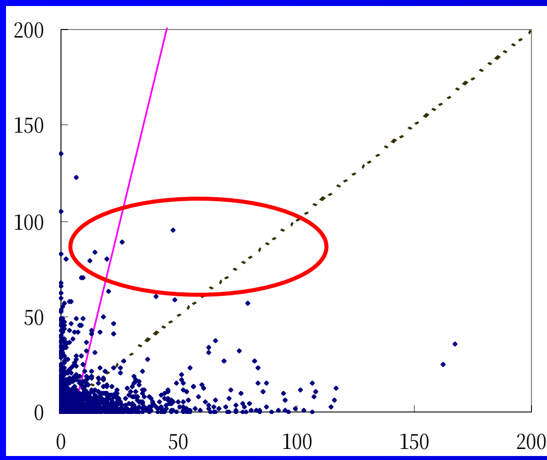
AR



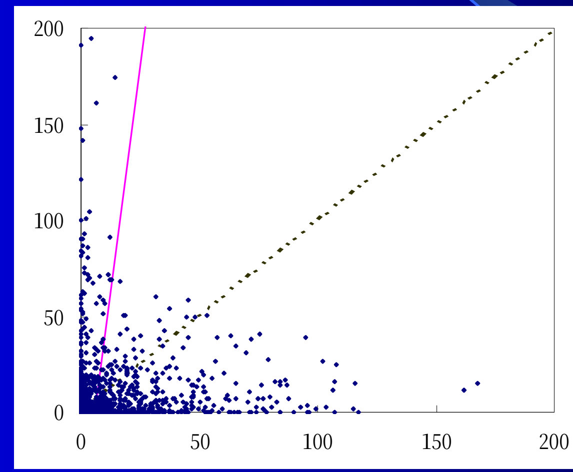
BR



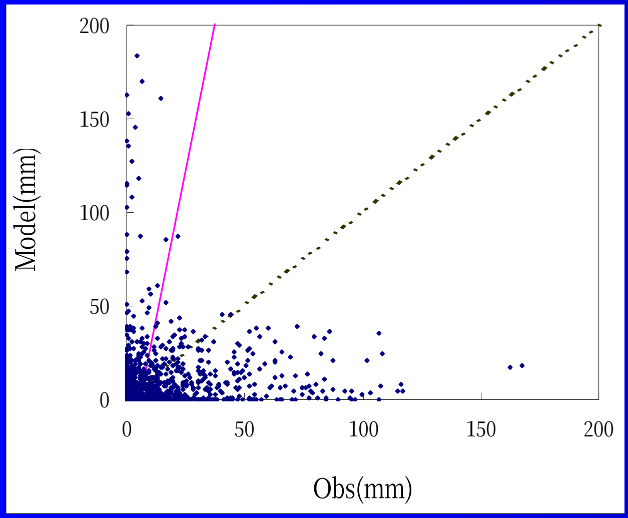
GR



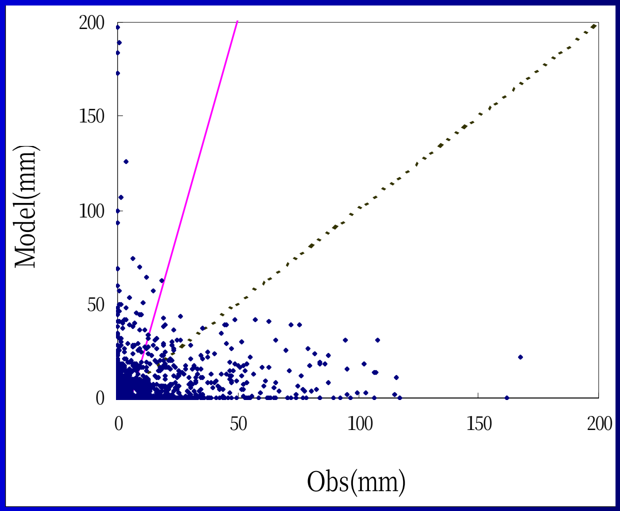
KG



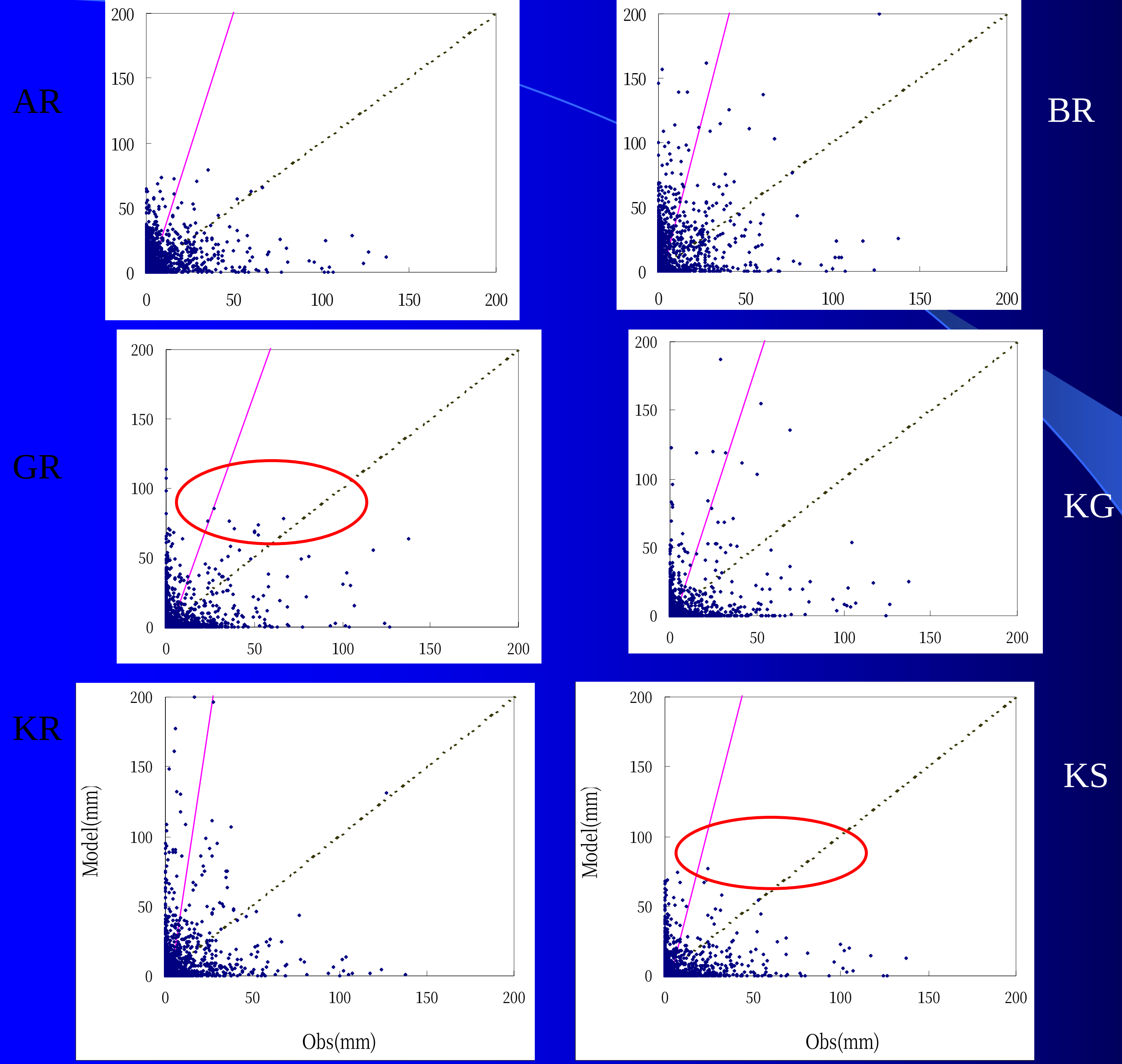
KR

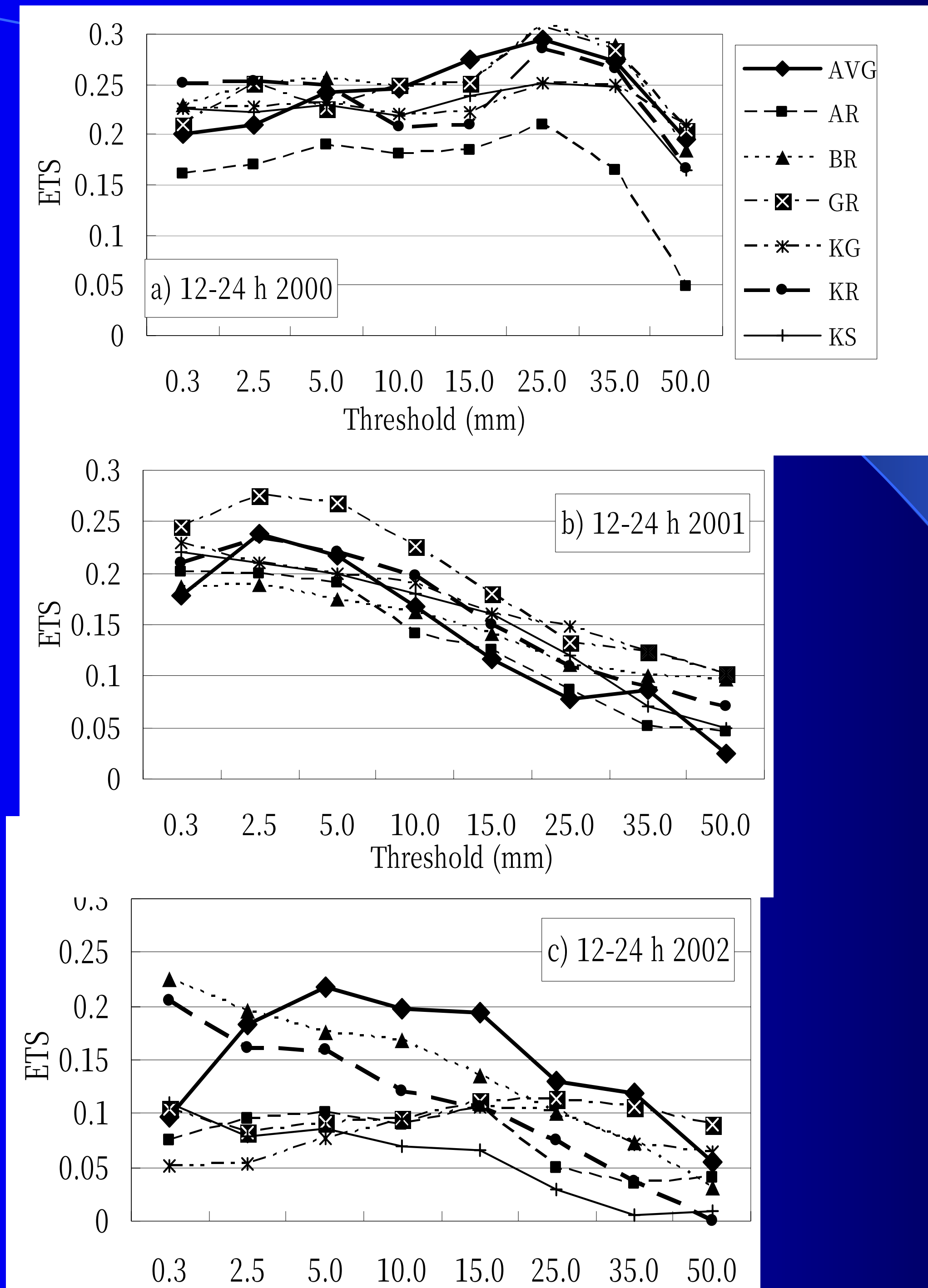


KS

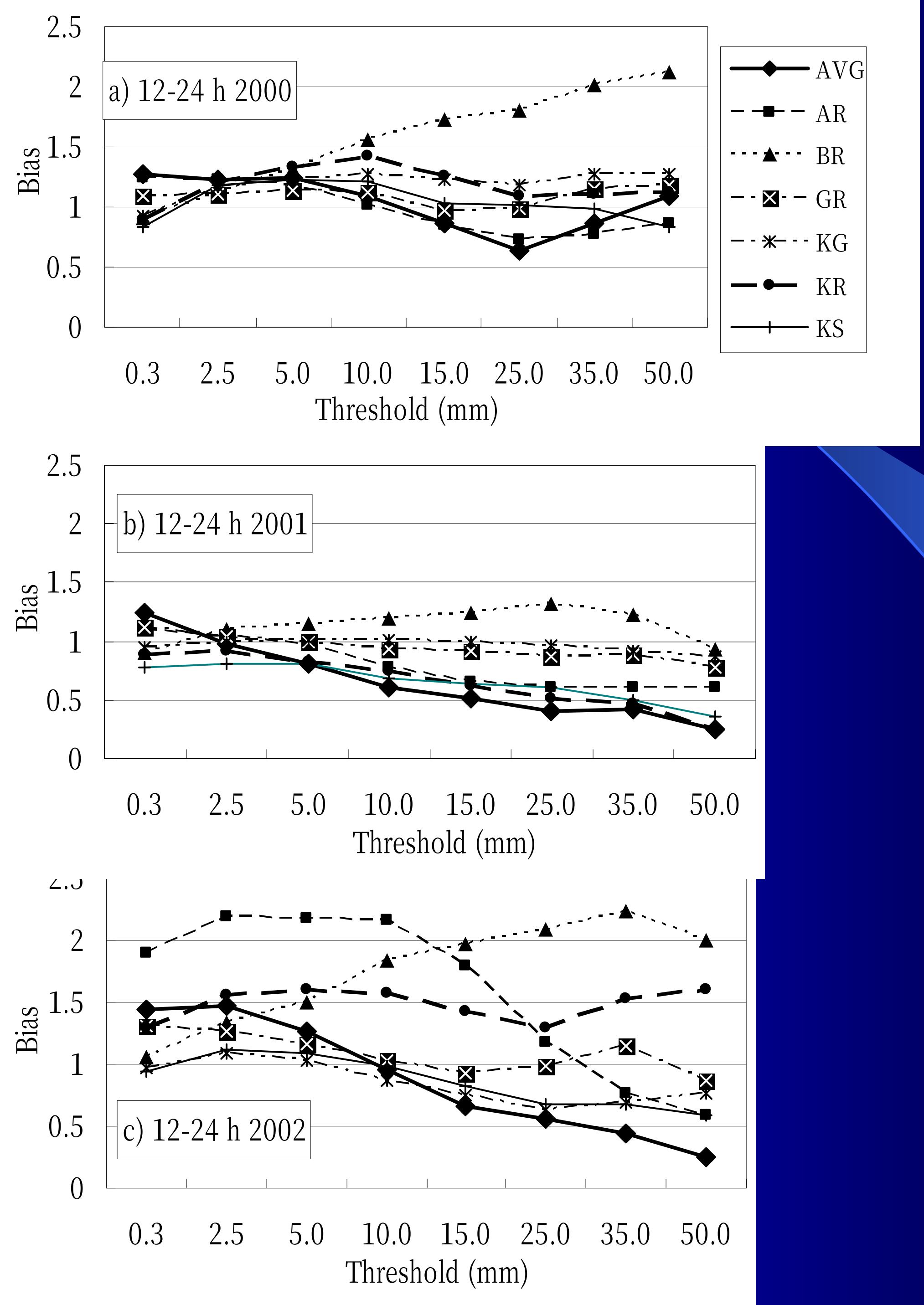


Observed vs. Forecasted Rainfall Amount for the 12-24 h Forecast during the 2002 Mei-Yu Season





a) 12-24 h 2000
ETS
0.3
0.25
0.2
0.15
0.1
0.05
0
0.3 2.5 5.0 10.0 15.0 25.0 35.0 50.0
Threshold (mm)
AVG
AR
BR
GR
KG
KR
KS
b) 12-24 h 2001
ETS
0.3
0.25
0.2
0.15
0.1
0.05
0
0.3 2.5 5.0 10.0 15.0 25.0 35.0 50.0
Threshold (mm)
c) 12-24 h 2002
ETS
0.25
0.2
0.15
0.1
0.05
0
0.3 2.5 5.0 10.0 15.0 25.0 35.0 50.0


a) 12-24 h 2000
b) 12-24 h 2001
c) 12-24 h 2002
Bias
Threshold (mm)
0.3
2.5
5.0
10.0
15.0
25.0
35.0
50.0
0
0.5
1
1.5
2
2.5
AVG
AR
BR
GR
KG
KR
KS

Ensemble rainfall forecast using a multiple linear regression (MLR) method: (Thanks to Dr. P.-J. Sheu)

Assume observed rainfall (O) can be expressed as a linear combination of MM5-forecasted rainfalls (M) as:

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ O_N \end{bmatrix} = \alpha \begin{bmatrix} (m_1)_1 \\ (m_1)_2 \\ (m_1)_3 \\ \vdots \\ (m_1)_N \end{bmatrix} + \beta \begin{bmatrix} (m_2)_1 \\ (m_2)_2 \\ (m_2)_3 \\ \vdots \\ (m_2)_N \end{bmatrix} + \gamma \begin{bmatrix} (m_3)_1 \\ (m_3)_2 \\ (m_3)_3 \\ \vdots \\ (m_3)_N \end{bmatrix} + \kappa \begin{bmatrix} (m_4)_1 \\ (m_4)_2 \\ (m_4)_3 \\ \vdots \\ (m_4)_N \end{bmatrix} + \delta \begin{bmatrix} (m_5)_1 \\ (m_5)_2 \\ (m_5)_3 \\ \vdots \\ (m_5)_N \end{bmatrix} + \varepsilon \begin{bmatrix} (m_6)_1 \\ (m_6)_2 \\ (m_6)_3 \\ \vdots \\ (m_6)_N \end{bmatrix} - \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ \vdots \\ r_N \end{bmatrix} \quad (1)$$

where m_1 is the first ensemble member, m_2 is the second ensemble member, and so on. N is the total number of forecast rainfall events during a Mei-Yu season.

The above equation can be written in a vector form as:

$$\vec{O} = \alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{r} \quad (2)$$

Then the rainfall forecast error is

$$\vec{r} = \alpha\vec{m}_1 + \beta\vec{m}_2 + \gamma\vec{m}_3 + \kappa\vec{m}_4 + \delta\vec{m}_5 + \varepsilon\vec{m}_6 - \vec{O} \quad (3)$$

where $\alpha, \beta, \gamma, \kappa, \delta, \varepsilon$ is the weighting coefficient for each member.

The square of forecast error is

$$r^2 = \vec{r} \cdot \vec{r} = (\alpha\vec{m}_1 + \beta\vec{m}_2 + \gamma\vec{m}_3 + \kappa\vec{m}_4 + \delta\vec{m}_5 + \varepsilon\vec{m}_6 - \vec{O})^2 \quad (4)$$

Then a minimization of rainfall forecast error in a least square sense can be obtained by setting

$$\frac{\partial r^2}{\partial \alpha} = 0 = 2\vec{m}_1 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5a)}$$

$$\frac{\partial r^2}{\partial \beta} = 0 = 2\vec{m}_2 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5b)}$$

$$\frac{\partial r^2}{\partial \gamma} = 0 = 2\vec{m}_3 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5c)}$$

$$\frac{\partial r^2}{\partial \kappa} = 0 = 2\vec{m}_4 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5d)}$$

$$\frac{\partial r^2}{\partial \delta} = 0 = 2\vec{m}_5 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5e)}$$

$$\frac{\partial r^2}{\partial \varepsilon} = 0 = 2\vec{m}_6 \cdot (\alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{O}) \quad \text{(5f)}$$

After some arrangements, we can have

$$
\begin{bmatrix}
\vec{m}_1\cdot\vec{m}_1 & \vec{m}_1\cdot\vec{m}_2 & \vec{m}_1\cdot\vec{m}_3 & \vec{m}_1\cdot\vec{m}_4 & \vec{m}_1\cdot\vec{m}_5 & \vec{m}_1\cdot\vec{m}_6 \\
\vec{m}_2\cdot\vec{m}_1 & \vec{m}_2\cdot\vec{m}_2 & \vec{m}_2\cdot\vec{m}_3 & \vec{m}_2\cdot\vec{m}_4 & \vec{m}_2\cdot\vec{m}_5 & \vec{m}_2\cdot\vec{m}_6 \\
\vec{m}_3\cdot\vec{m}_1 & \vec{m}_3\cdot\vec{m}_2 & \vec{m}_3\cdot\vec{m}_3 & \vec{m}_3\cdot\vec{m}_4 & \vec{m}_3\cdot\vec{m}_5 & \vec{m}_3\cdot\vec{m}_6 \\
\vec{m}_4\cdot\vec{m}_1 & \vec{m}_4\cdot\vec{m}_2 & \vec{m}_4\cdot\vec{m}_3 & \vec{m}_4\cdot\vec{m}_4 & \vec{m}_4\cdot\vec{m}_5 & \vec{m}_4\cdot\vec{m}_6 \\
\vec{m}_5\cdot\vec{m}_1 & \vec{m}_5\cdot\vec{m}_2 & \vec{m}_5\cdot\vec{m}_3 & \vec{m}_5\cdot\vec{m}_4 & \vec{m}_5\cdot\vec{m}_5 & \vec{m}_5\cdot\vec{m}_6 \\
\vec{m}_6\cdot\vec{m}_1 & \vec{m}_6\cdot\vec{m}_2 & \vec{m}_6\cdot\vec{m}_3 & \vec{m}_6\cdot\vec{m}_4 & \vec{m}_6\cdot\vec{m}_5 & \vec{m}_6\cdot\vec{m}_6
\end{bmatrix}_{6\times 6}
\begin{bmatrix}
\alpha \\ \beta \\ \gamma \\ \kappa \\ \delta \\ \varepsilon
\end{bmatrix}_{6\times 1}
=
\begin{bmatrix}
\vec{m}_1\cdot\vec{O} \\ \vec{m}_2\cdot\vec{O} \\ \vec{m}_3\cdot\vec{O} \\ \vec{m}_4\cdot\vec{O} \\ \vec{m}_5\cdot\vec{O} \\ \vec{m}_6\cdot\vec{O}
\end{bmatrix}_{6\times 1}
\qquad (6)
$$

A **B** **C**

Thus a minimization of square of forecast rainfall error can be written as

$$\mathbf{AB = C}$$

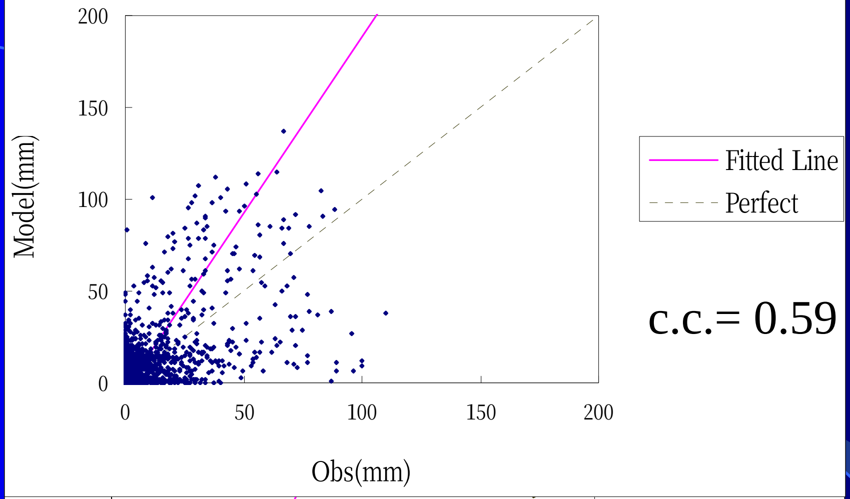
So

$$\mathbf{B = A^{-1}C}$$

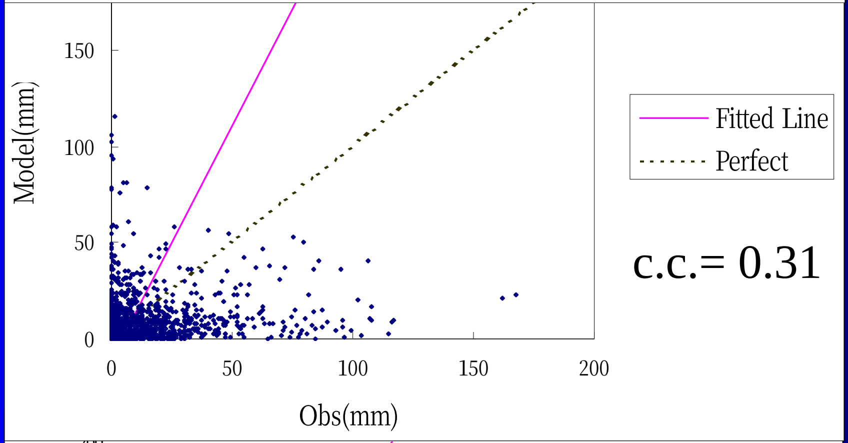
where vector B whose element (α , β , γ , κ , δ , ε) is the weighting coefficient of each ensemble member.

Observed vs. Ensemble Forecasted Rainfall Amount for the 12-24 h Forecast during the three Mei-Yu Season

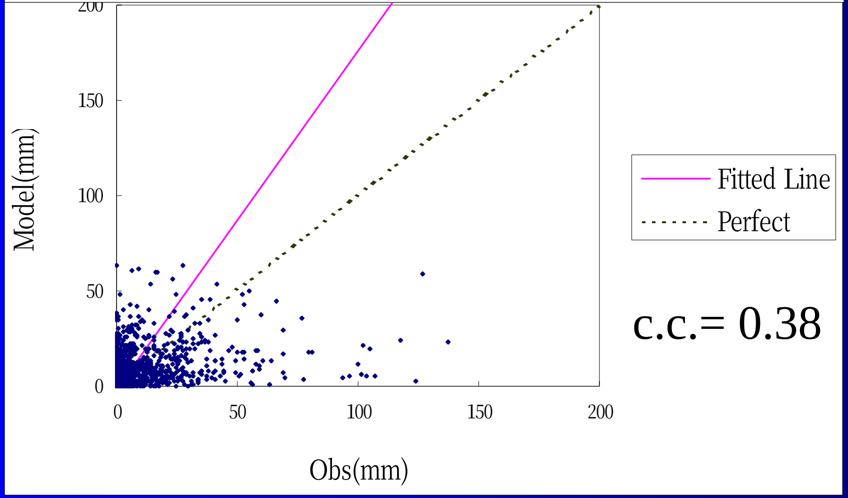
2000

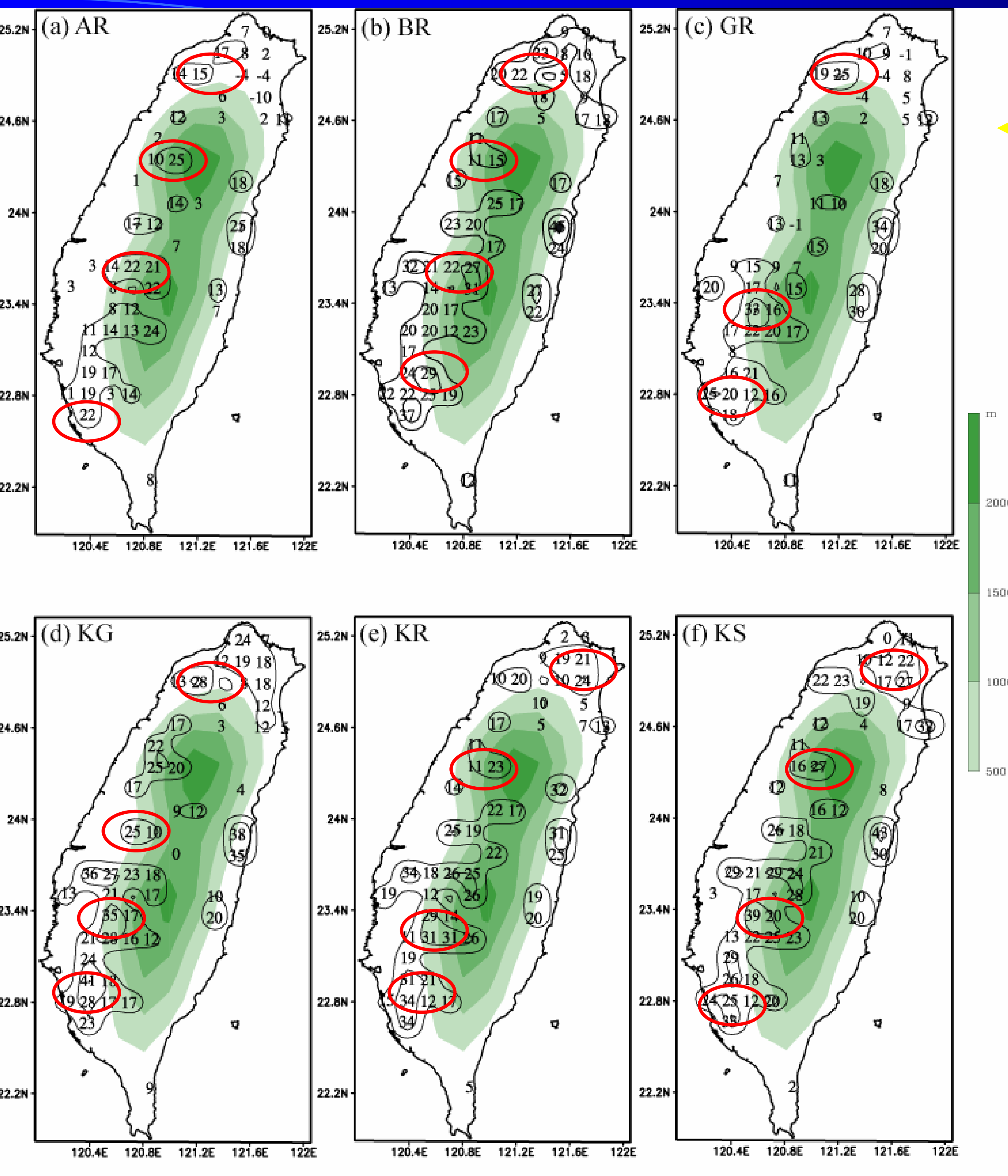


2001



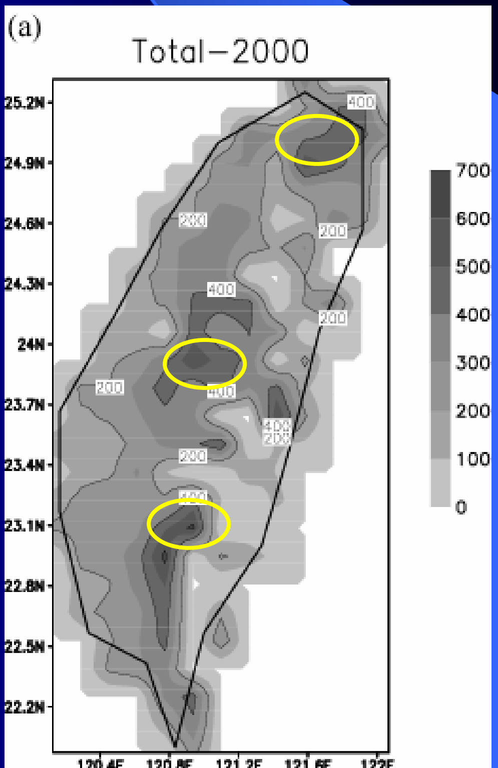
2002

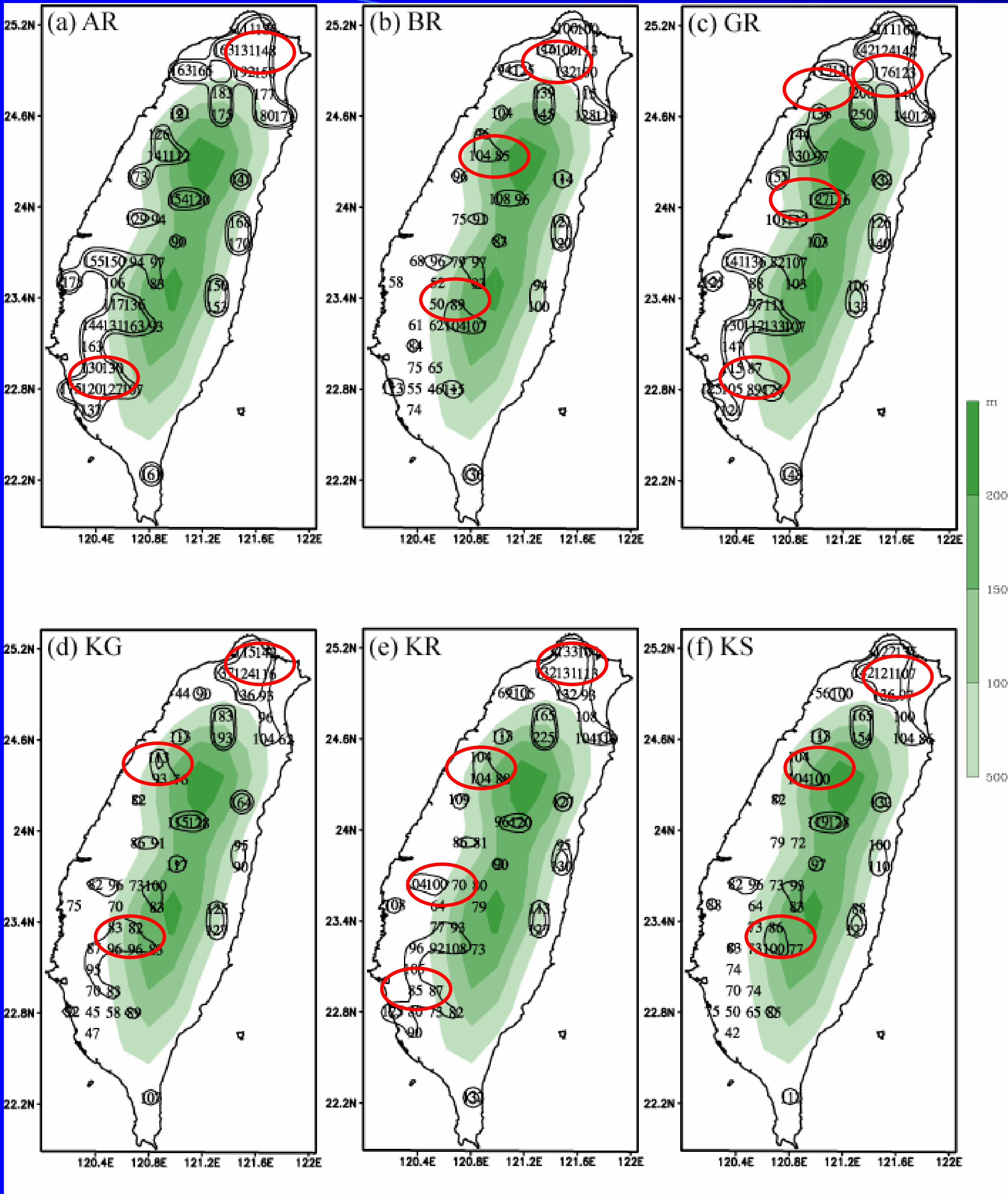




Horizontal ETS Distribution For 12-24 h fcst

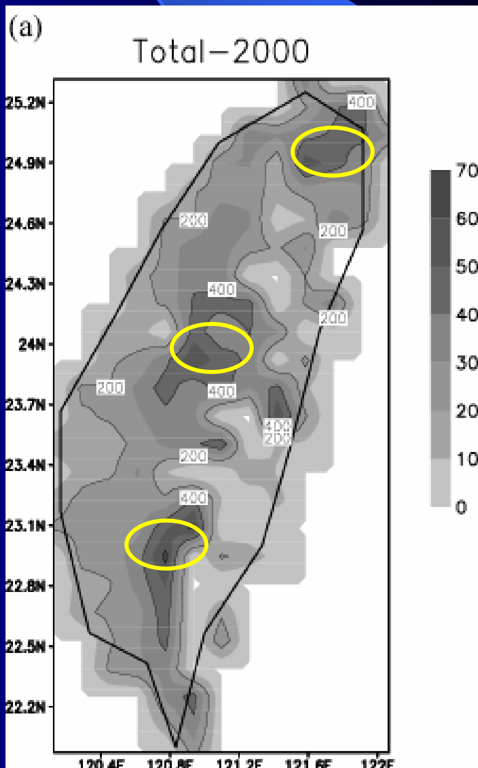
Observed Rainfall Distribution

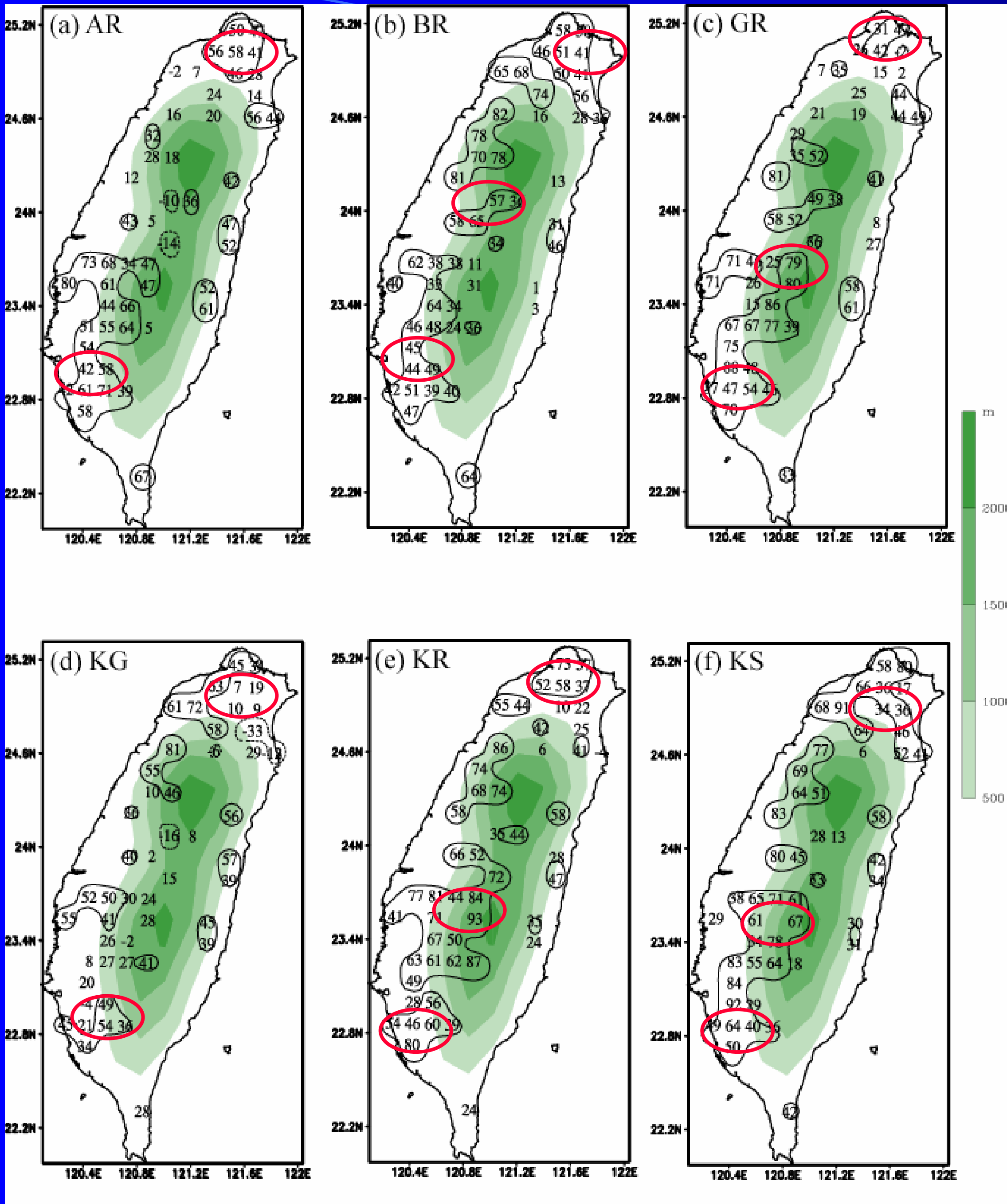




Horizontal BS Distribution For 12-24 h fcst

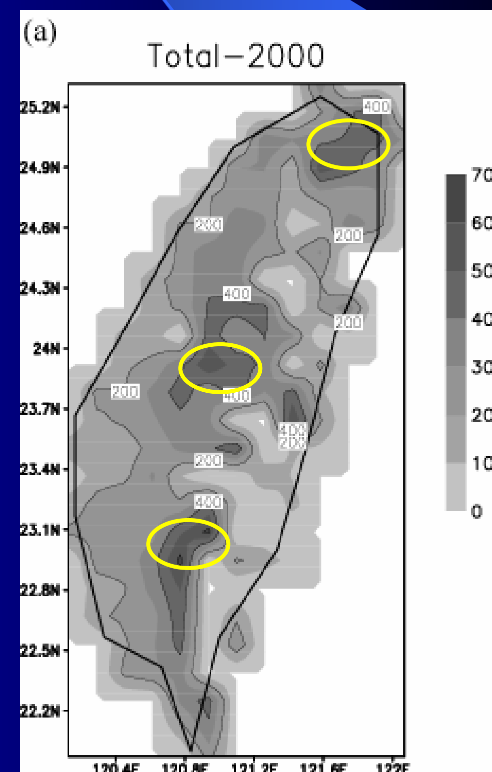
Observed Rainfall Distribution



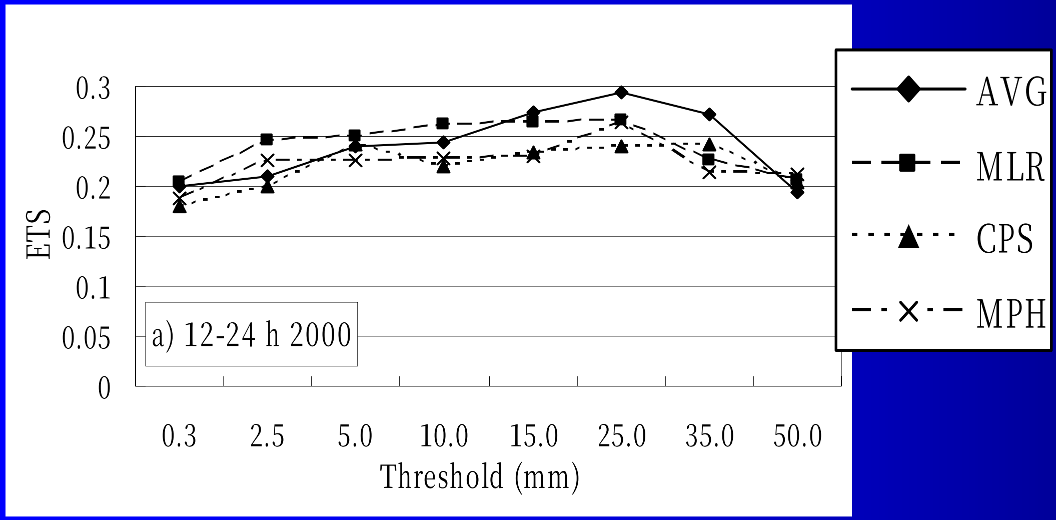


Distribution of Weighting Coefficient for 12-24 h fcst

Observed Rainfall Distribution



ETS Scores for Four Ensemble 12-24 h Forecasts in 2000



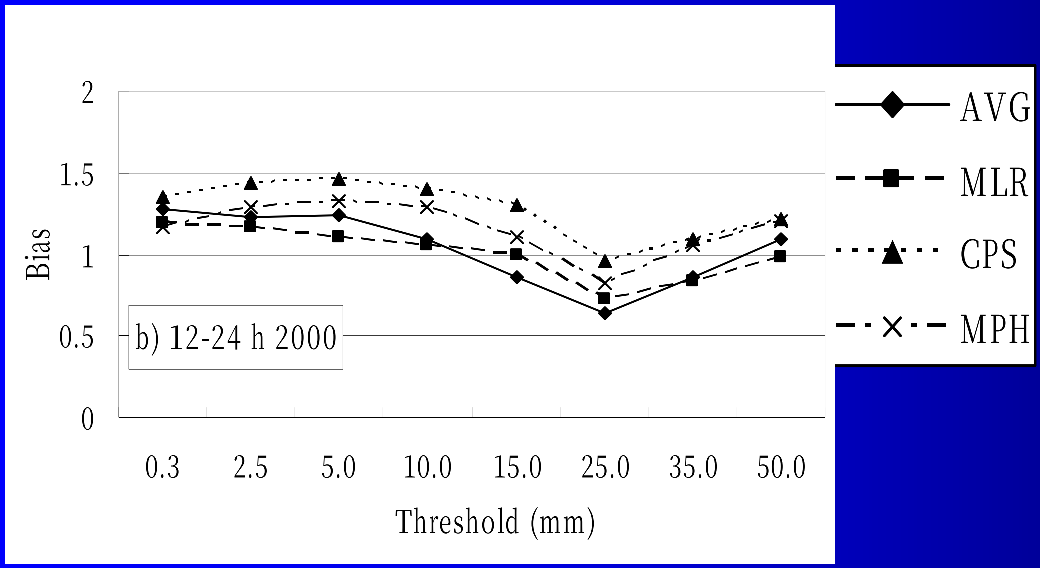
AVG: Same weighting for Six members

MLR: Multiple Linear Regression

CPS: Same weighting for Three CPS members

MPH: Same weighting for Three Microphysics members

BS Scores for Four Ensemble 12-24 h Forecasts in 2000



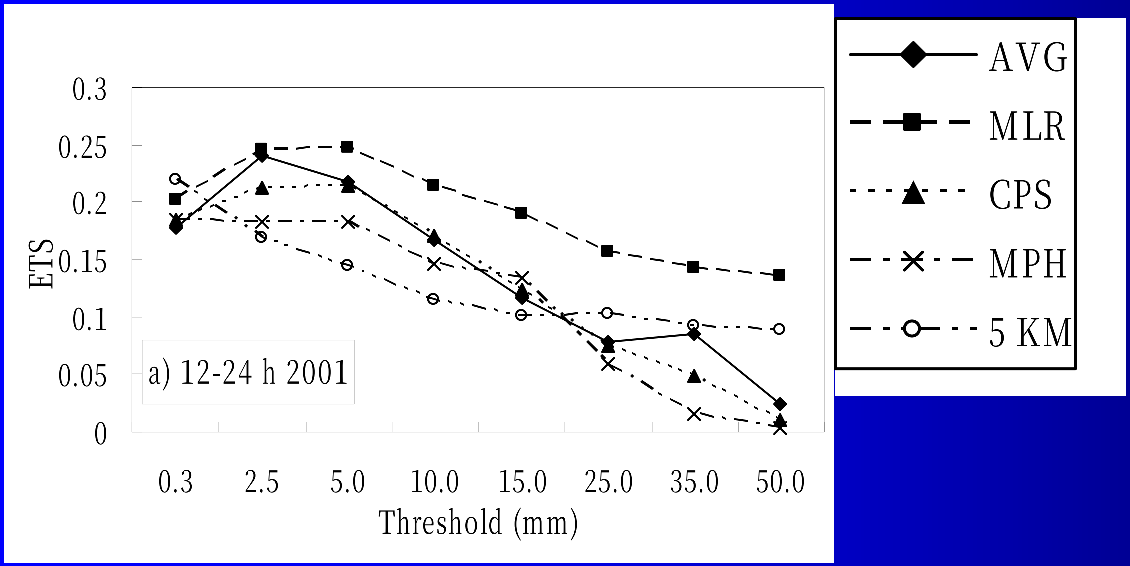
AVG: Same weighting
for Six members

MLR: Multiple Linear
Regression

CPS: Same weighting
for Three CPS members

MPH: Same weighting
for Three Microphysics
members

Coarse-Resolution Ensemble vs High-Resolution Forecast



AVG: Same weighting for Six members

MLR: Multiple Linear Regression

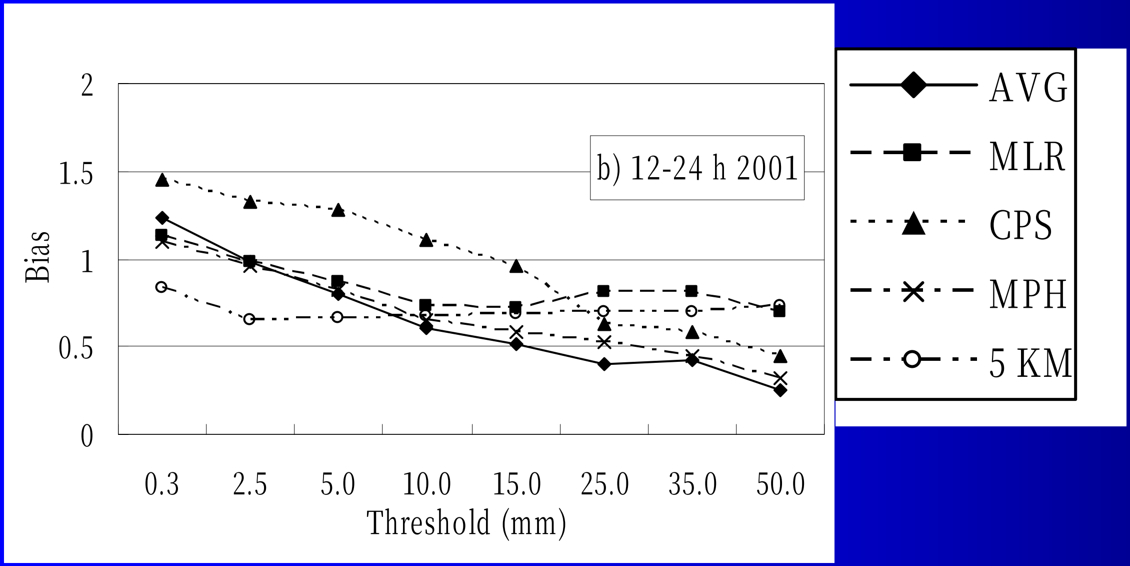
CPS: Same weighting for Three CPS members

MPH: Same weighting for Three Microphysics members

5 KM: Single 5-KM Run

(Provided by Hong in GIMEX)

Coarse-Resolution Ensemble vs High-Resolution Forecast



AVG: Same weighting for Six members

MLR: Multiple Linear Regression

CPS: Same weighting for Three CPS members

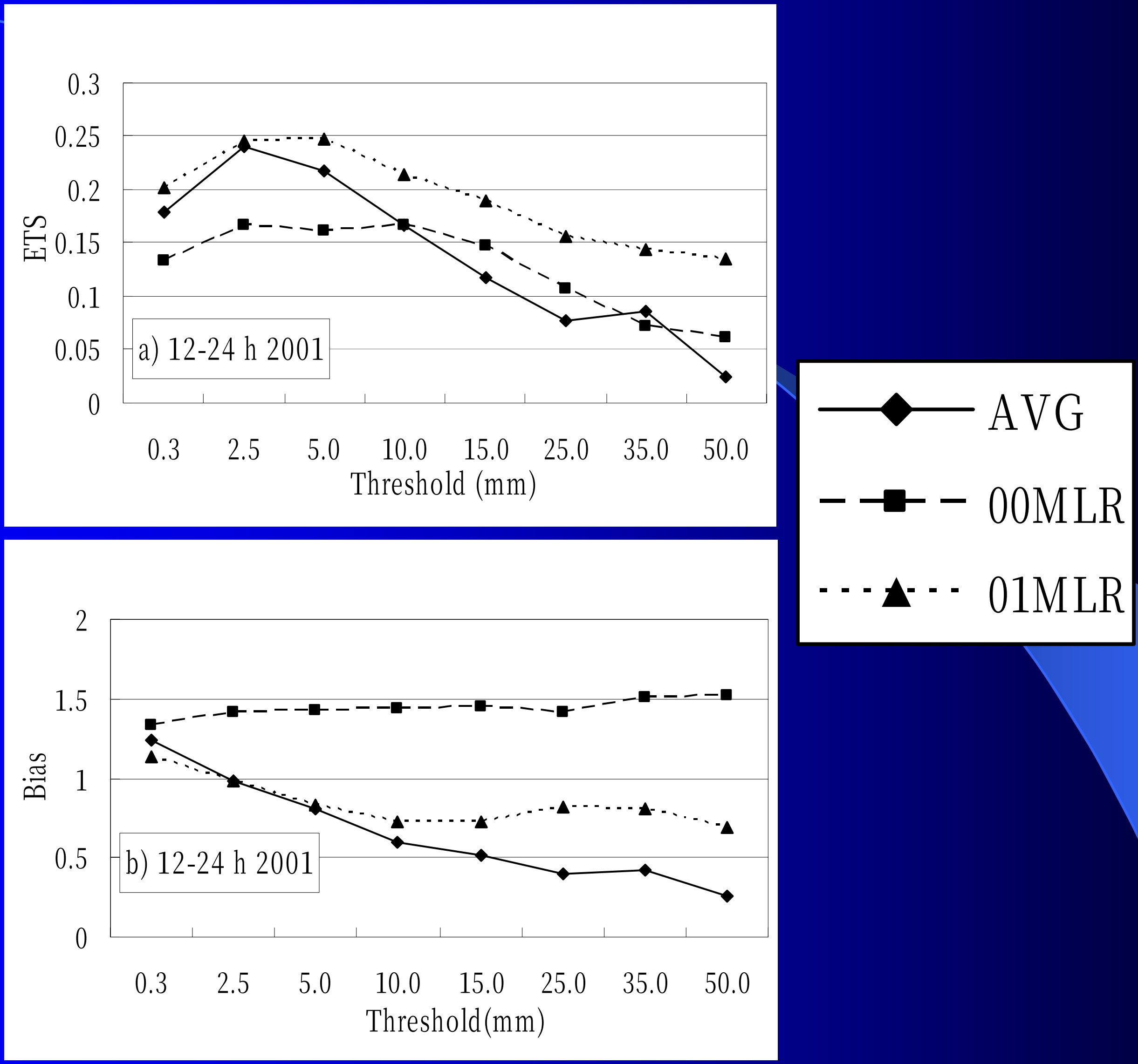
MPH: Same weighting for Three Microphysics members

5 KM: Single 5-KM Run

(Provided by Hong in GIMEX)

ETS

Bias



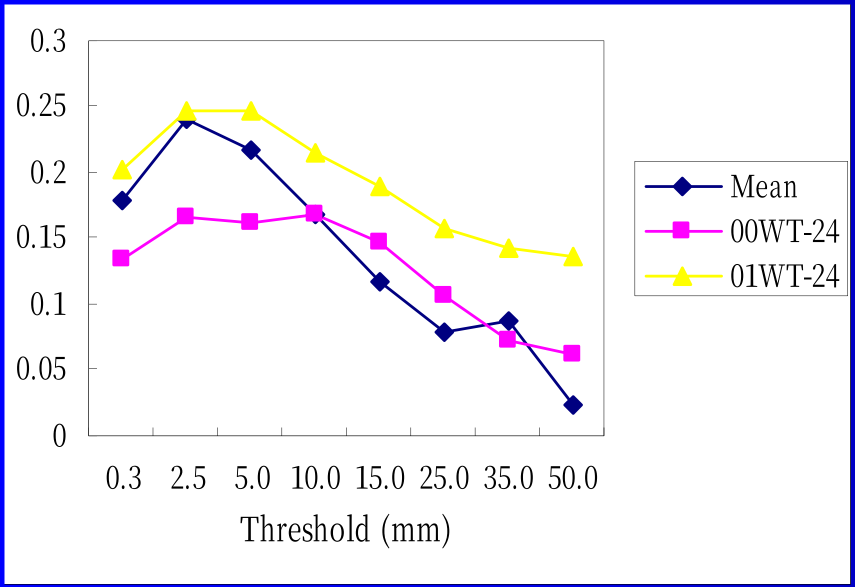
AVG: Same Weighting for Six Members

00MLR: Use the MLR Weighting from Year 2000

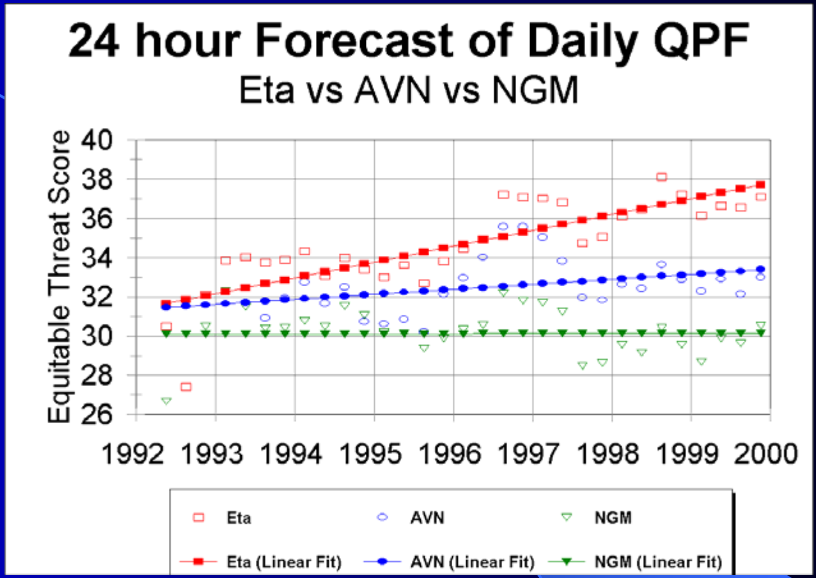
01MLR: Use the MLR Weighting from Year 2001 (Current Year)

Taiwan's Mei-Yu Season MLR Ensemble Forecasting

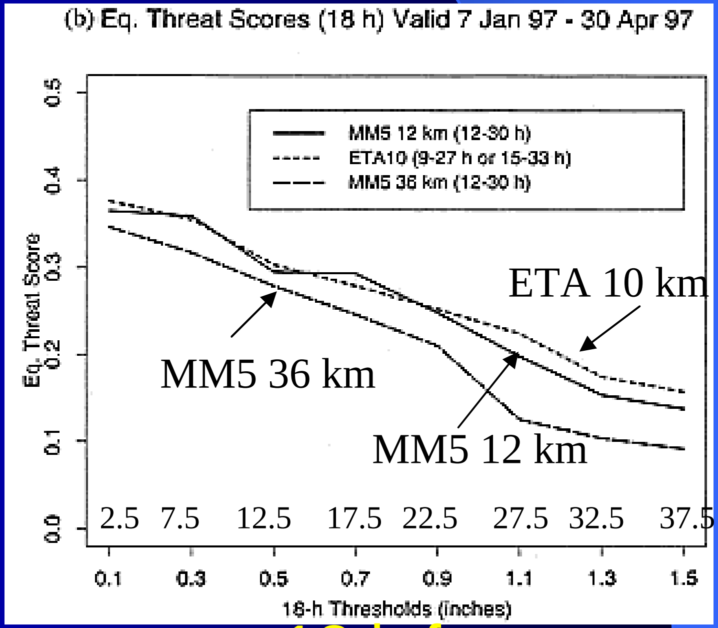
12-24 h 2001 (MM5 15 km)



NCEP Model Forecast for Threshold = 0.25 mm



Washington's Cold Season (Mass @ UW)



18 h fcst

Summary

(1) For rainfall occurrence forecast, most members had better skill over the NE mountain area, NW coastal plan, central mountain slope, and SW coastal plain. These areas were also regions of more accumulated rainfalls during the Mei-Yu seasons.

(2) An ensemble forecast of rainfall using the MLR method had the best ETS and BS performance for all rainfall thresholds, and it persistently outperformed the AVG forecast with 6 members having the same weighting.

(3) The MLR ensemble forecasting applies more weighting over regions of higher ETS scores, thus producing a better predictive skill for all (particularly for high) precip. thresholds.

Summary

(4) The MLR ensemble forecasting with weighting from previous years still had similar trends of ETS and BS to those determined from current-year weighting, albeit with less skill.

→ Taiwan's rainfalls during the Mei-Yu seasons may have some climatological characteristics, and the MLR ensemble forecasting may be able to capture this climatological attribute.

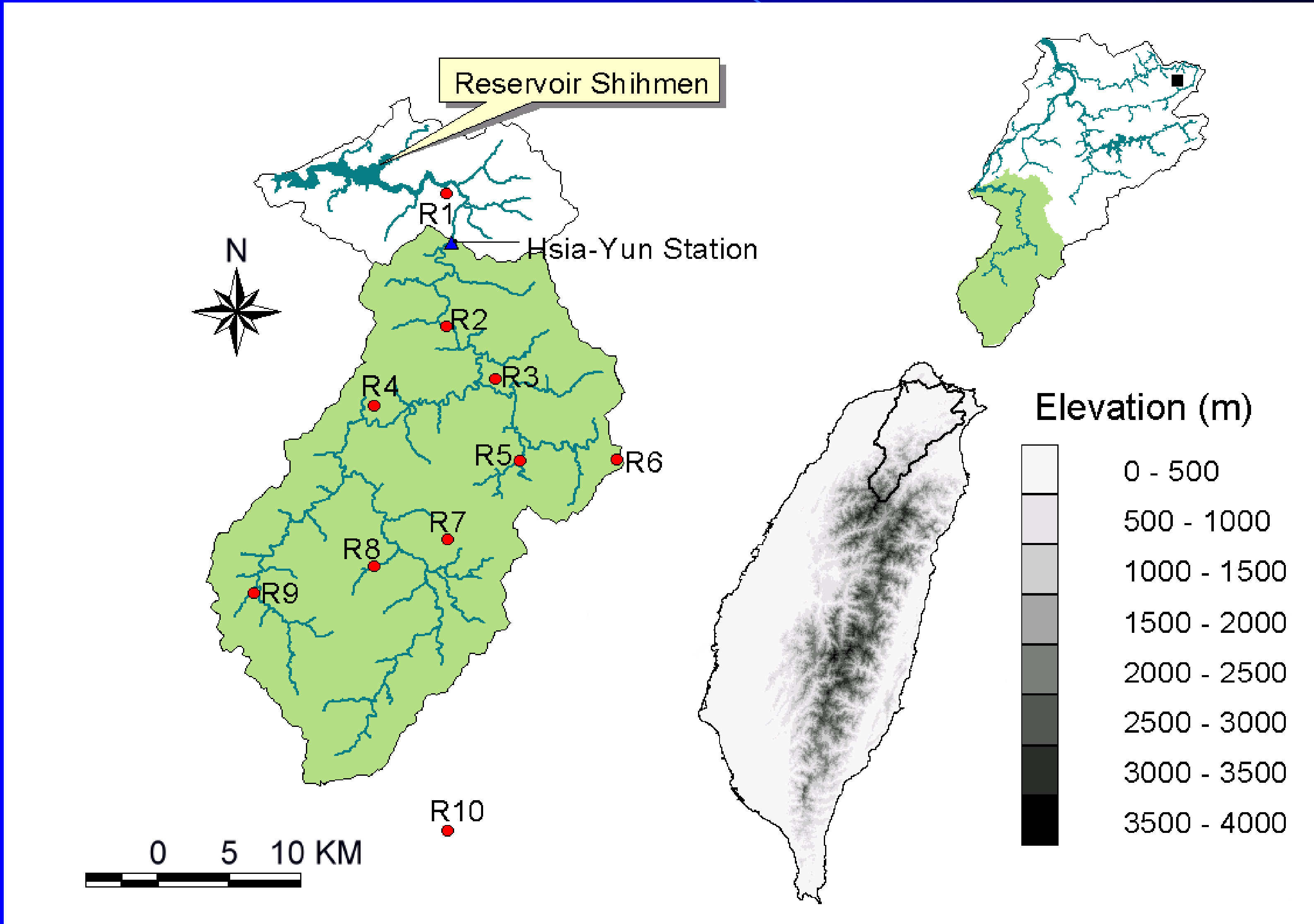
(5) Coarse-resolution ensemble forecast may outperform single high-resolution forecast, if a proper ensemble mean is taken.

Part III: River Runoff Simulation (Coupling MM5 with FLO-2D)

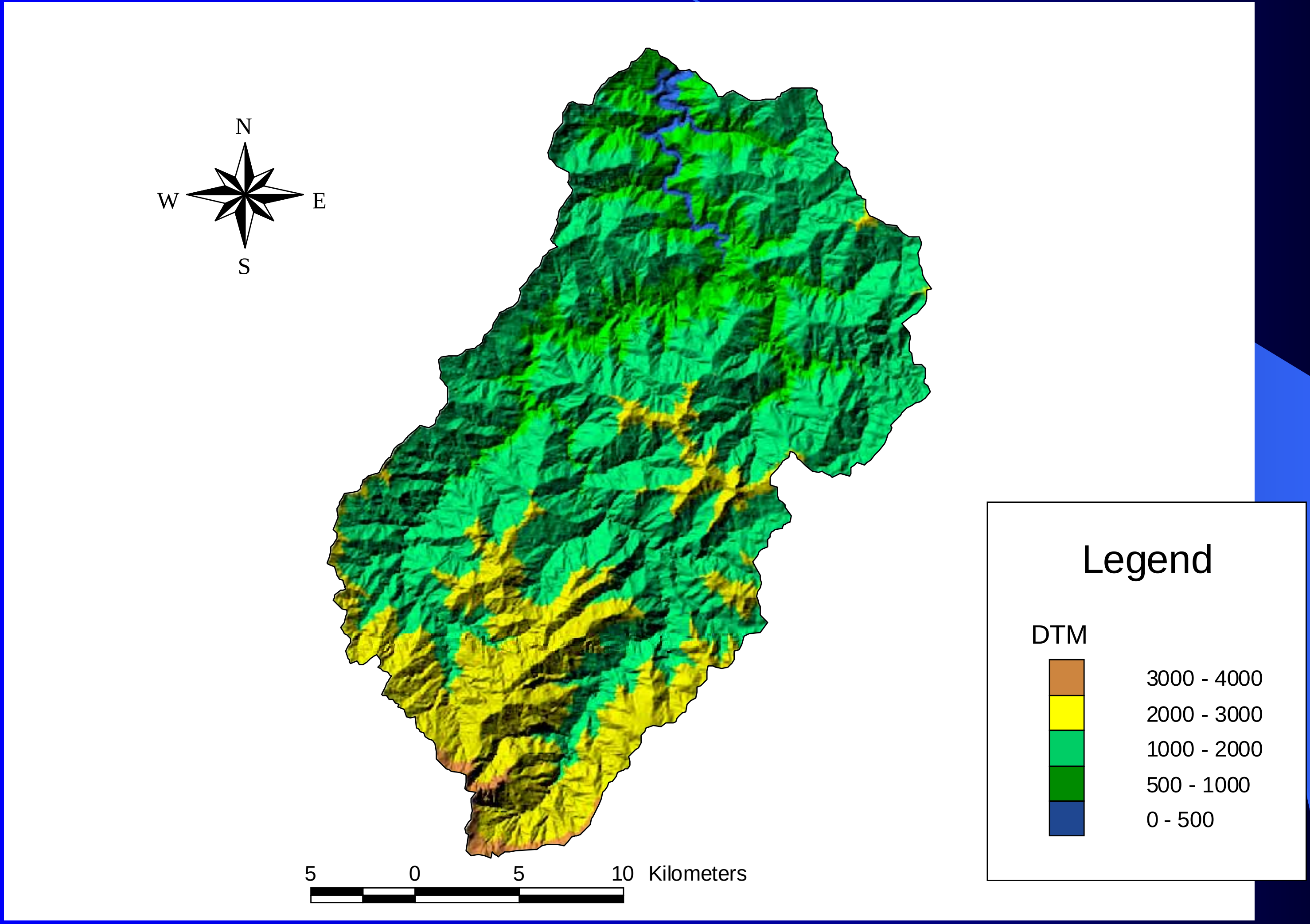
In Cooperation with Ming-Hsu Li

Ref: Li, M.-H., M.-J. Yang, R. Soong, and H.-L. Huang, 2005: Simulating typhoon floods with gauge data and mesoscale modeled rainfall in a mountainous watershed. *J. Hydrometeor.*, **6**, 306–323.

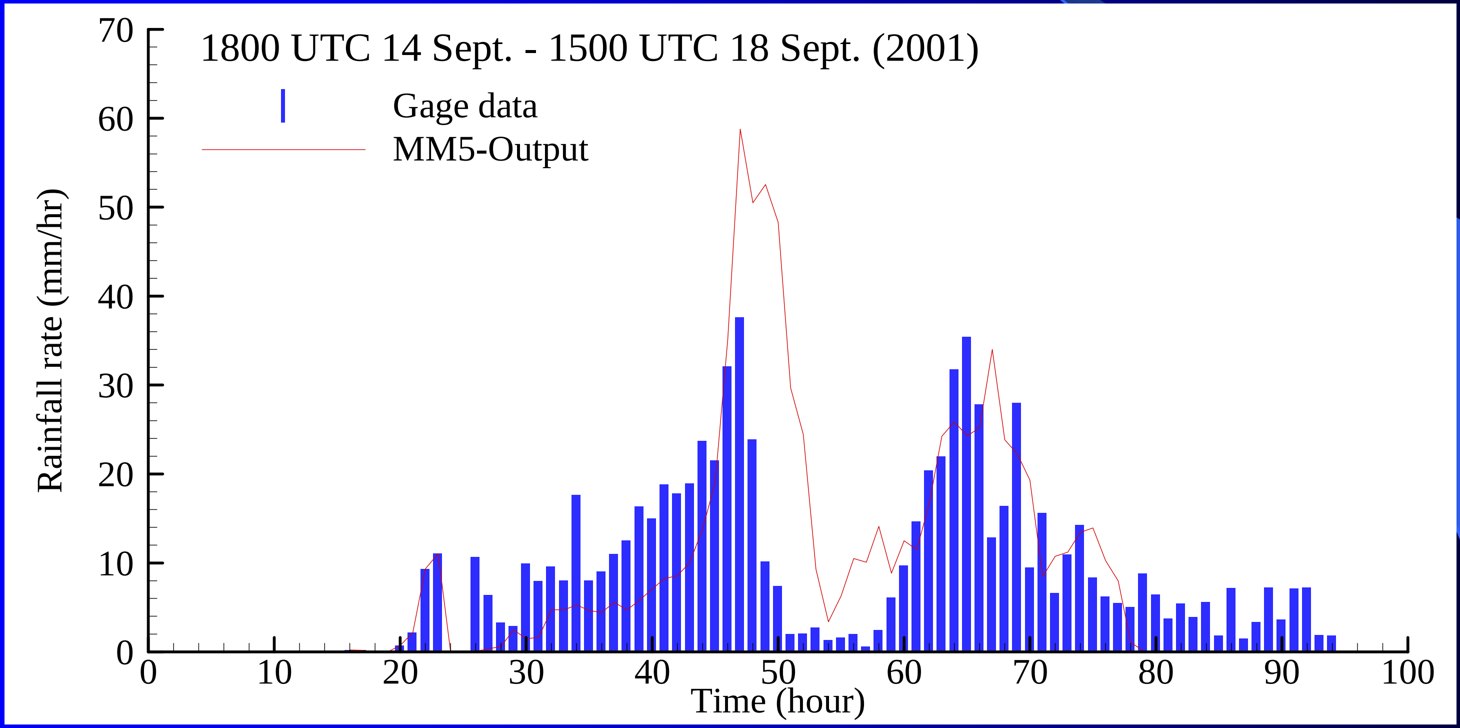
Shiehmen Basin



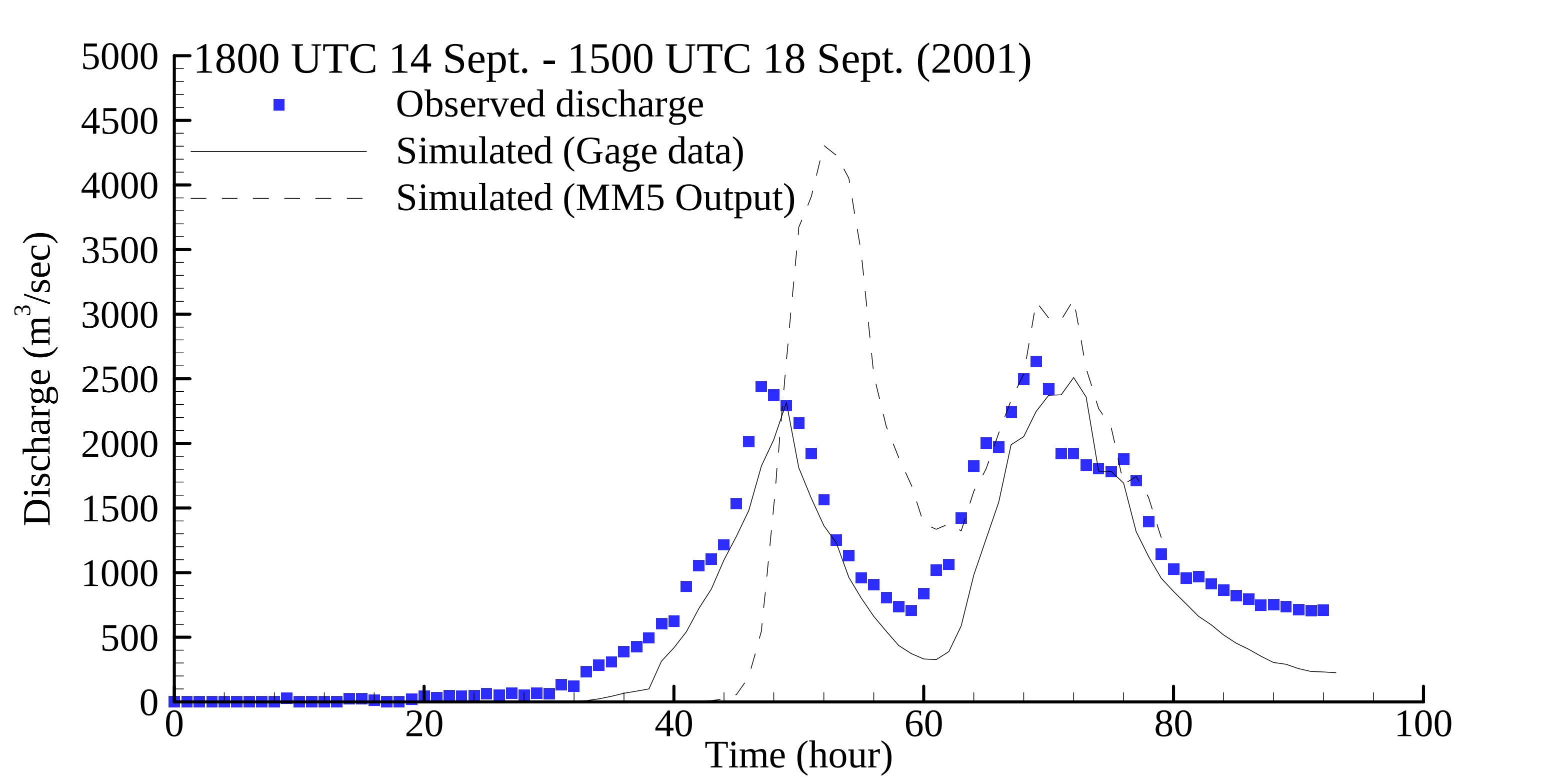
DTM of Shihmen Watershed



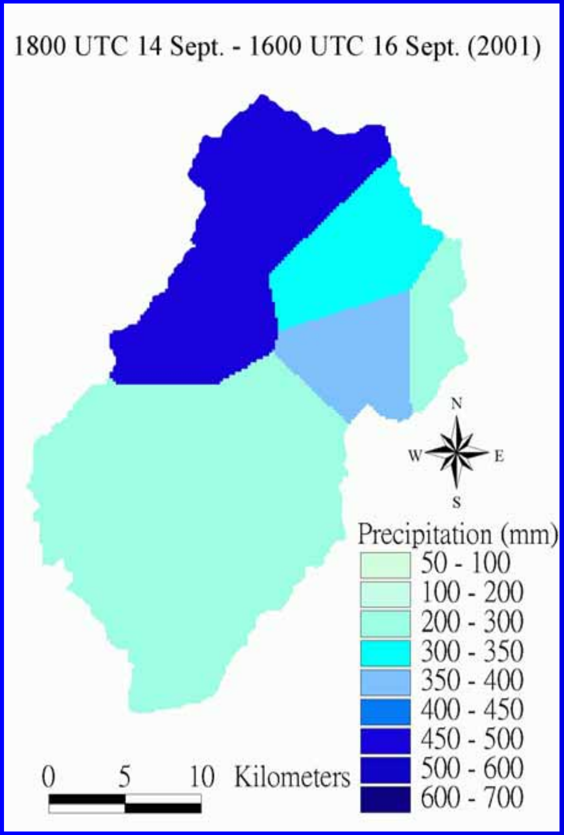
Rainfall Comparison (Basin Average)



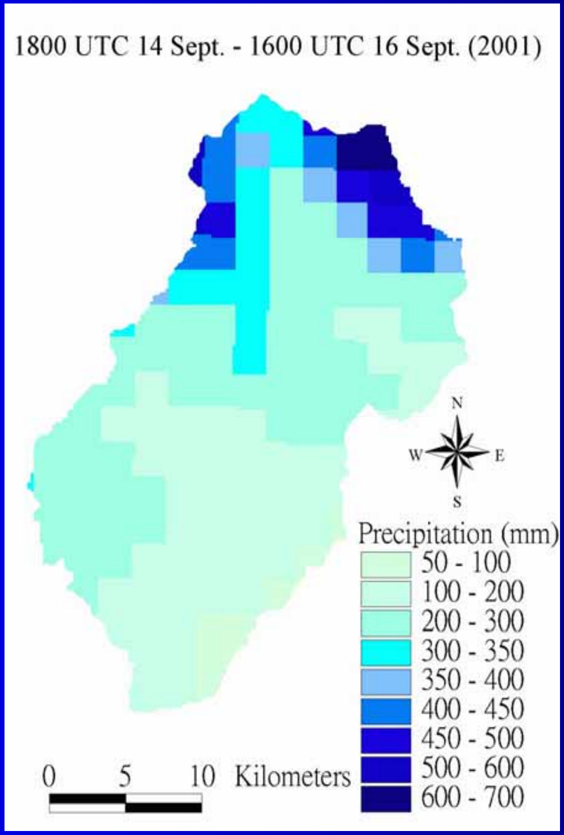
Flow Discharge Comparison (Basin Average)



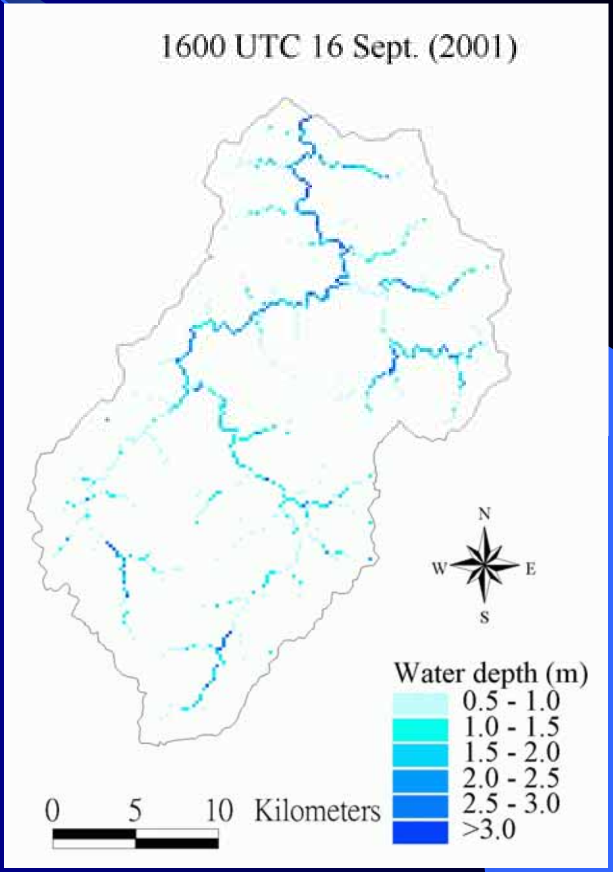
Gauge Rainfall



MM5 Rainfall



Simulated River Depths by MM5 Rainfall



定量降水預報之未來展望

- 0~6小時預報→即時觀測(雷達)外延估計
  6~48小時預報→NWP產品的妥善應用
- 找出數值模式定量降水預報的系統性偏差, 並加上適當修正.
- 參考多家數值模式定量降水預報產品, 並進行系集預報.
- 引用機率預報概念提供定量降水預報, 以呈現中小尺寸降水現象的間歇性及不確定性.