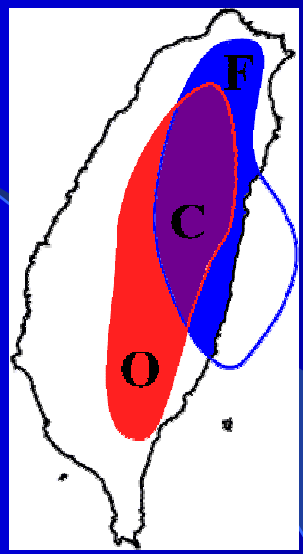
Rainfall Forecast of Cumulus Parameterization Schemes in the Taiwan Area



Ming-Jen Yang 楊明仁
Institute of Hydrological Sciences
National Central University

Research Objectives

1. How well do cumulus parameterization schemes (CPSs) perform under various synoptic environments?
2. What is the general applicability of CPSs when they are applied in Taiwan area other than those environments tested by the developers?
3. Can a rainfall forecast based on an ensemble of CPSs provide a better precipitation prediction?

Comparison of four CPSs

	Parameterization	Dynamic Control	Static Control	Feedback	Trigger
AK	**Anthes-Kuo (1977)**	• vertically integrated moisture convergence (M_t)	• moist adiabat	• parabolic heating profile • moistening profile depending on environmental relative humidity	• $M_t > 3\times10^{-5} kg\ m^{-2}s^{-1}$ • stability check • $\Delta\sigma = 0.3$ cloud depth
GR	**Grell (1993)**	• quasi-equilibrium	• moist adiabat • downdraft • no entrainment	• compensating subsidence • detrainment of cloud water-ice throughout the cloud layer	• $\partial A/\partial t > 0$ • lifting depth <50 mb • 150-mb cloud depth • $M_t > 0$
KF	**Kain-Fritsch (1993)**	• CAPE-based • CAPE / τ , $\tau \approx 30$ min	• 1D entraining- detraining cloud model • downdraft • precipitation efficiency depending on wind shear • ice microphysics	• compensating subsidence • detrainment of cloud water-ice throughout the cloud layer	• stability check • temperature perturbation • 4-km cloud depth
BM	**Betts-Miller (1986)**	• adjustment toward reference profiles of convective equilibrium	• reference sounding: T_r and q_r	• $(T - T_r)/\tau$ • $(q - q_r)/\tau$	• stability check • 290-mb cloud depth

A: cloud work function, CAPE: convective available potential energy, τ: adjustment time.

AG: Ensemble of the four CPSs

From Kuo et al. (1996)

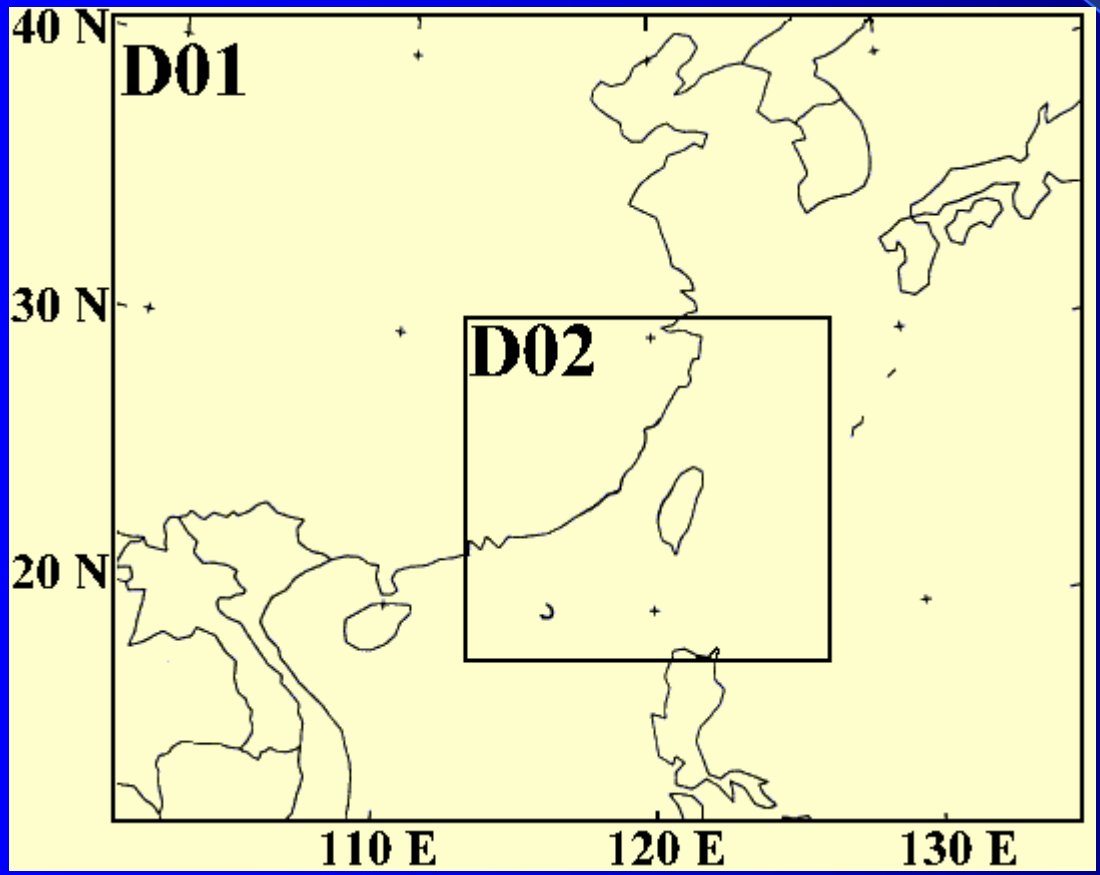
Summary of rainfall cases

Case	Description	Model initialization time	Category
1	Cold-air outbreak	0000 UTC 11 Jan. 1999	Cool Season
2	Autumn cold front	0000 UTC 6 Oct. 1998	
3	Spring rainfall	0000 UTC 18 Feb. 1999	Warm Season
4	Summer thunderstorm	1200 UTC 27 Aug. 1998	
5	Typhoon Otto	0000 UTC 4 Aug. 1998	Typhoon
6	Mei-Yu front	0000 UTC 27 May 1999	Mei-Yu

MM5 model physics

Item	Description
Version	Version 2.11
Vertical levels	27 levels
Microphysics	Simple Ice（Dudhia 1989）
PBL	Blackadar (1979）
Radiation	Dudhia (1989）
I. C.	CWB global model analysis
B.C.	CWB global model forecast
Forecast time	36 hours

MM5 Configuration



Grid size

D1：45 km

D2：15 km

Grid points

D1：71X81

D2：91X91

Evaluation Method

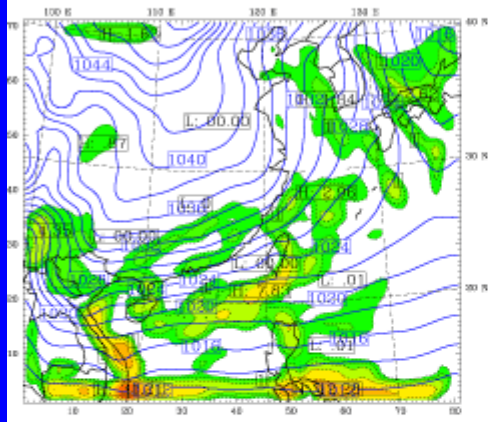
- First, model predictions are compared with observation analyses for the synoptic-scale meteorological features.
- Second, precipitation forecast over the Taiwan area is evaluated statistically to compare each CPS's prediction ability for rainfall area and rainfall amount.

Winter cold-air outbreak

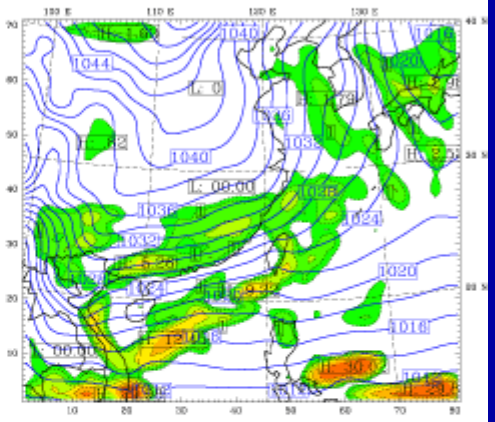
6-h accumulated rainfall

(00 UTC 12 Jan. 1999)

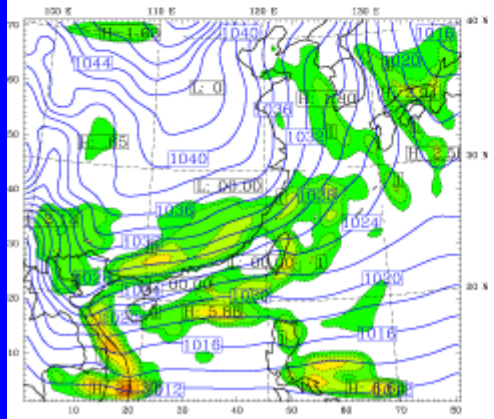
Anthes-Kuo



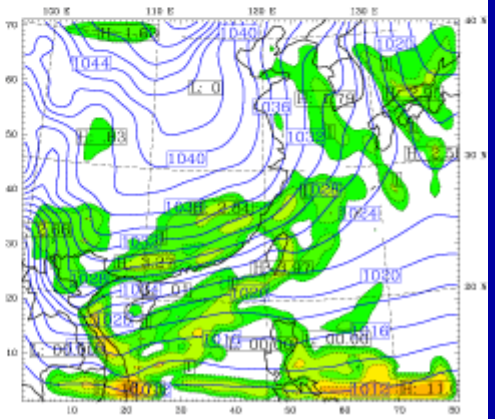
Betts-Miller

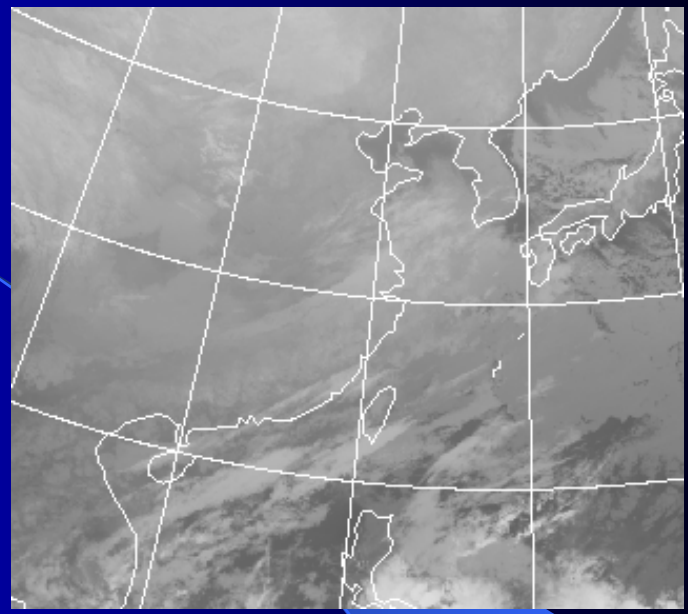


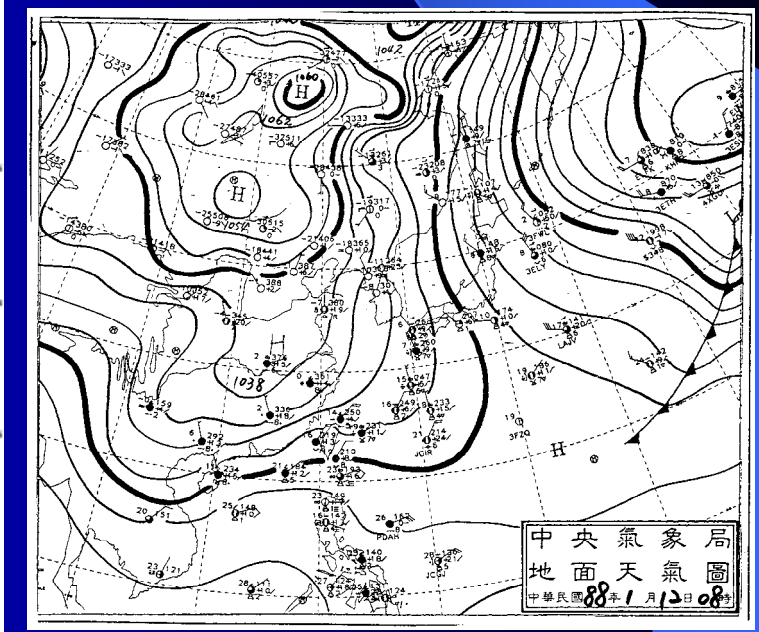
Grell



Kain-Fritsch

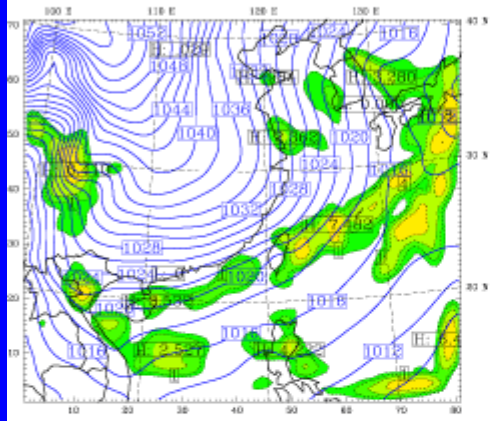




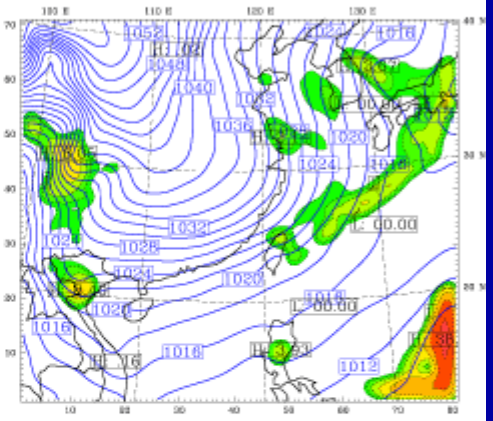


Spring rainfall
6-h accumulated rainfall
(00 UTC 18 Feb. 1999)

Anthes-Kuo



Betts-Miller



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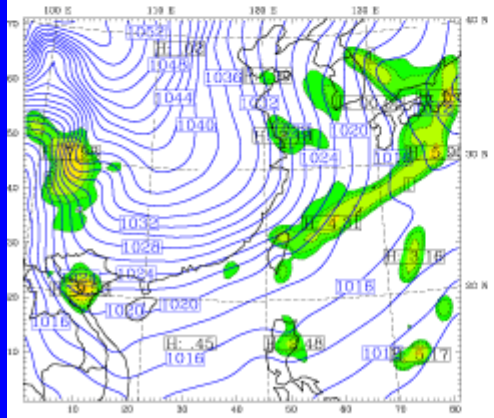
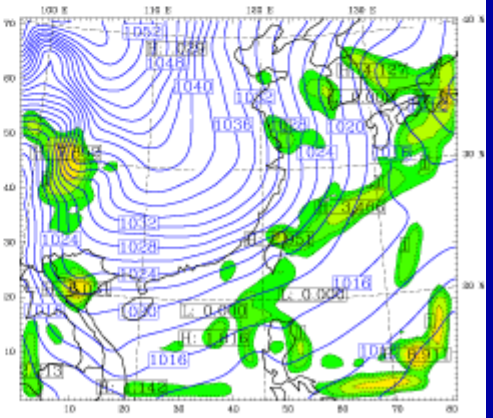
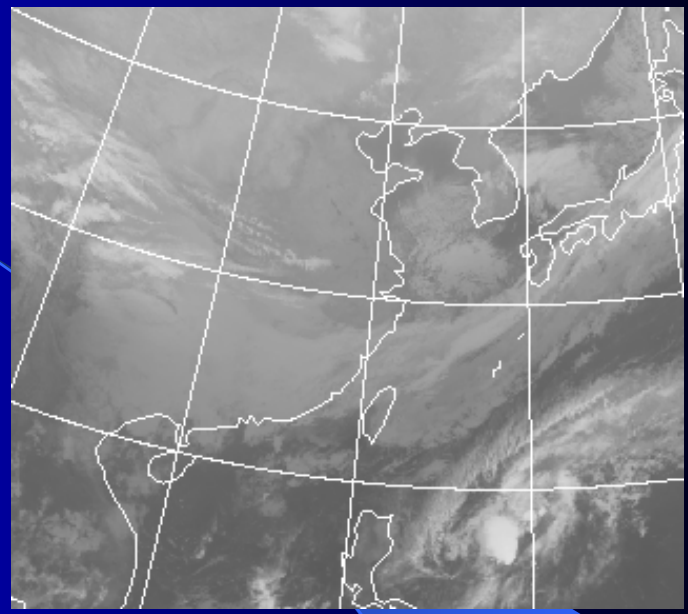
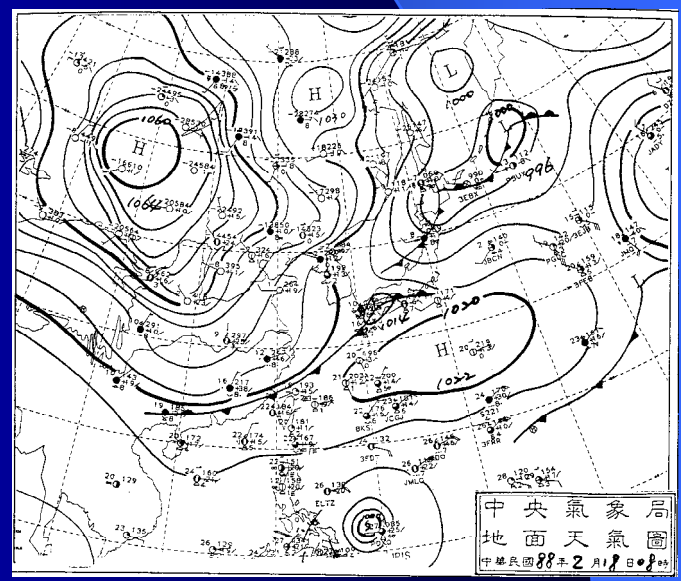


Kain-Fritsch



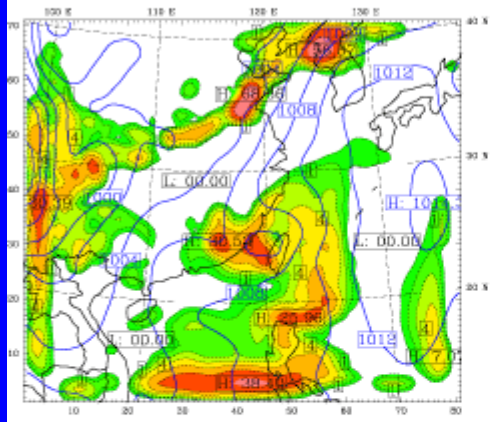




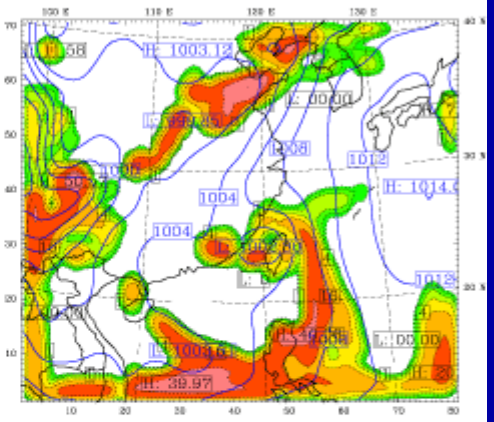
Typhoon Otto

6-h accumulated rainfall (18 UTC 4 Aug. 1998)

Anthes-Kuo



Betts-Miller



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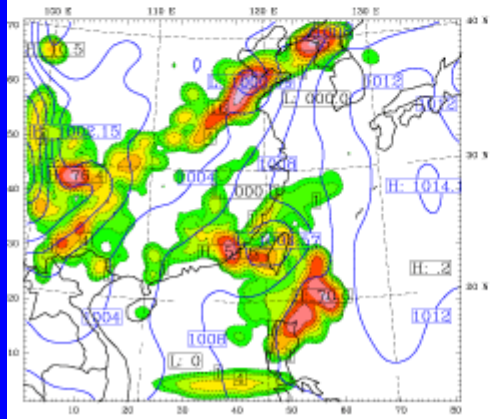

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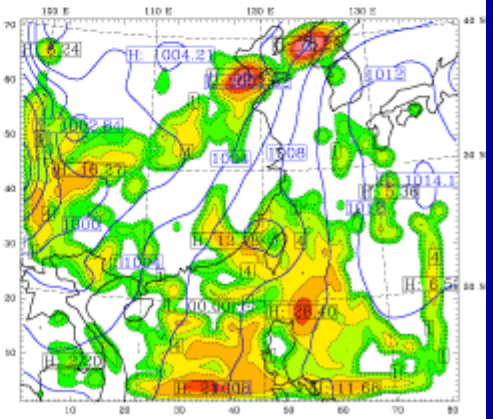
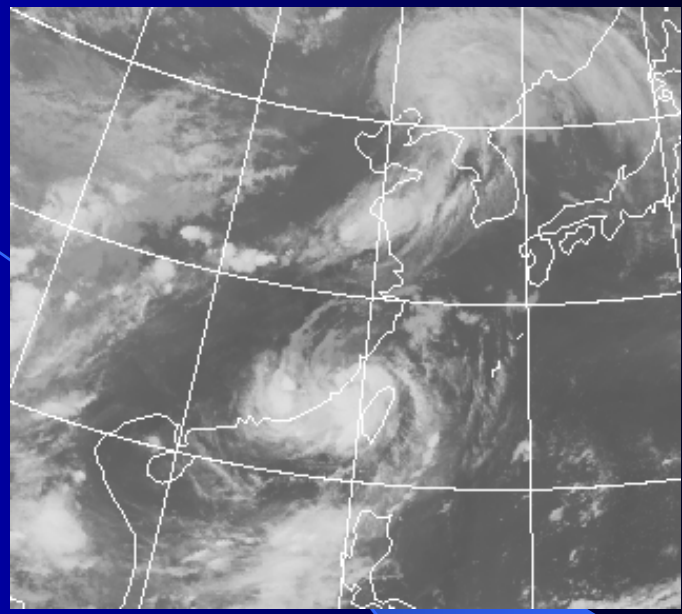
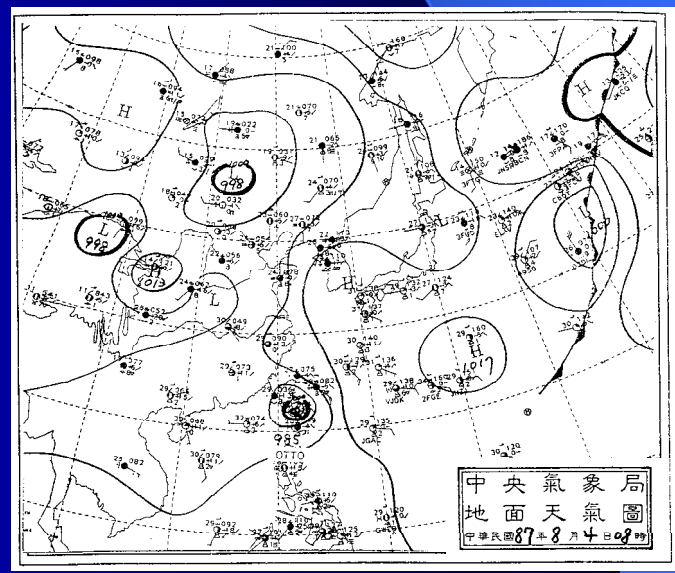


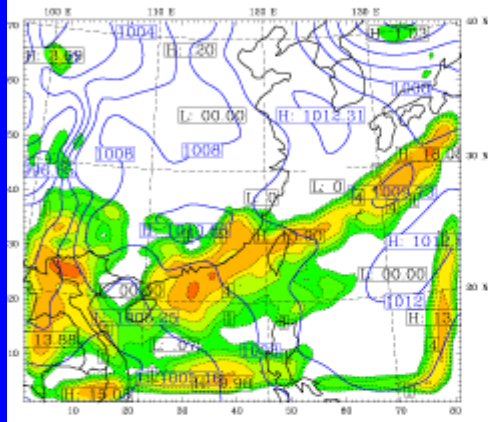




Mei-Yu front

6-h accumulated rainfall (00 UTC 28 May 1999)

Anthes-Kuo



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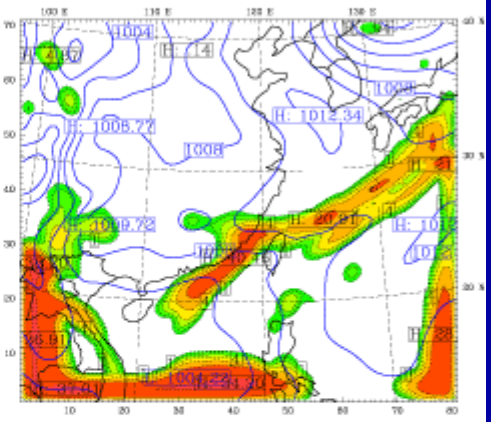

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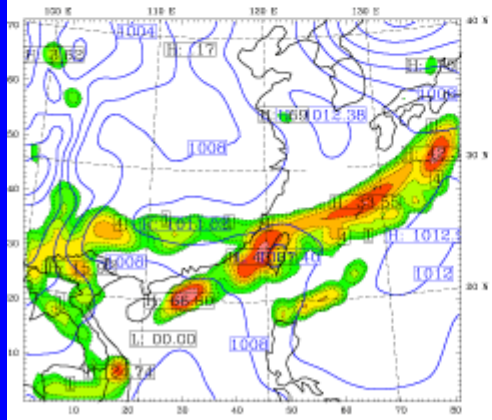

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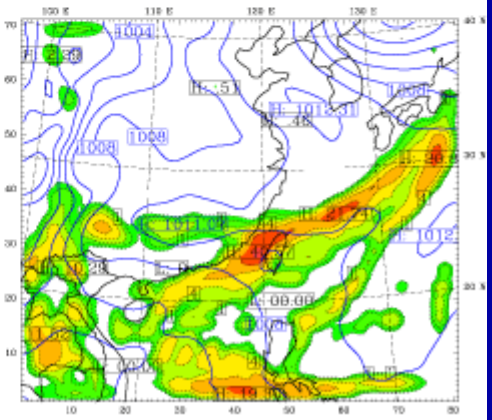
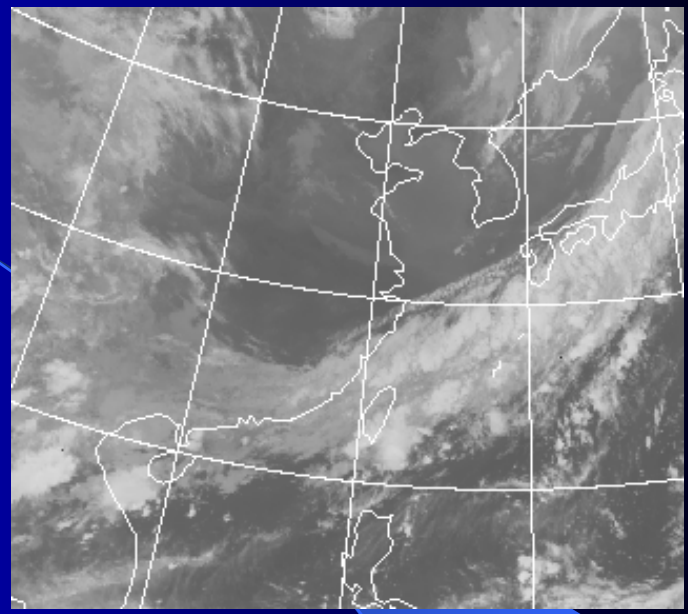
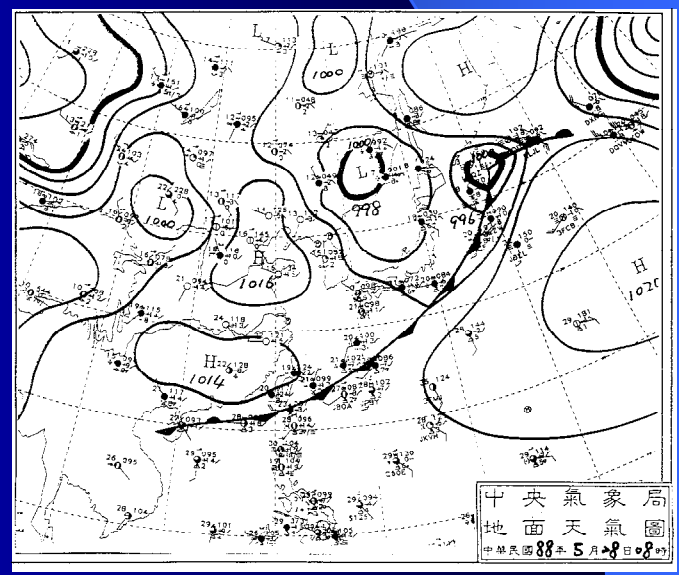
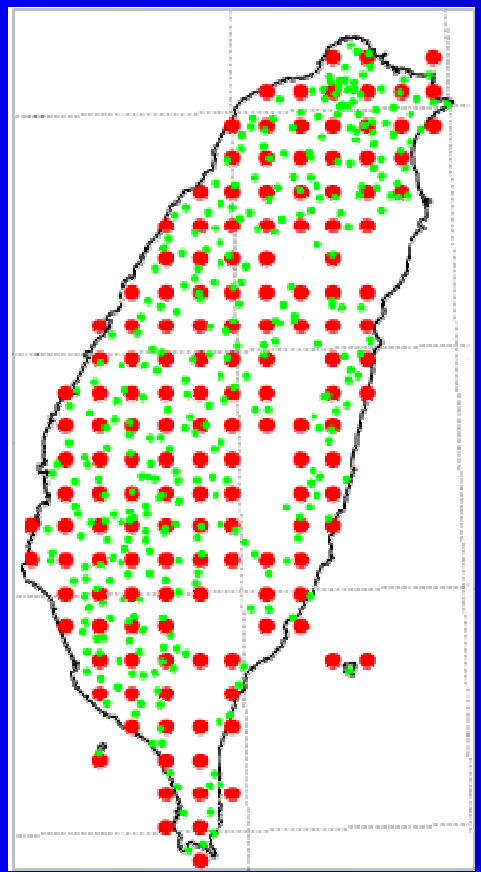






Objective Analysis



- Cressman (1959)

$$A_k^a = \frac{\sum_{i=1}^{N} W_{ki}(A_i^o)}{\sum_{i=1}^{N} W_{ki}} \qquad W = \frac{R^2 - r^2}{R^2 + r^2} \quad r < R \qquad W = 0 \quad r \geqq R$$

where R is the radius of influence (8.46 km)

r is the distance between a 15-km MM5 grid point and a rain gauge station

green dot: rain gauge station (343)

red dot: 15-km MM5 grid points (141)

Evaluation for rainfall area forecast

- **Threat Score (TS)**

$$\mathrm{TS} = \frac{H}{F + O - H} = \frac{A}{A + B + C}$$

- **Equitable Threat Score (ETS)**

$$\mathrm{ETS} = \frac{H - E}{F + O - H - E} = \frac{A - E}{A + B + C - E}$$

$$\mathrm{E} = \frac{FO}{N} = \frac{(A + B)(A + C)}{N}$$

- **Bias Score (BS)** $\mathrm{BS} = \frac{F}{O} = \frac{A + B}{A + C}$

- **Probability of Detection (POD)** $\mathrm{POD} = \frac{A}{A + C}$

- **False Alarm Rate (FAR)** $\mathrm{FAR} = \frac{B}{A + B}$

Rainfall Contingency Table

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

Evaluation for rainfall amount forecast

- Mean Relative Error (ME)
- Mean Absolute Error(MAE)
- Mean Relative Error Percentage (MEP)
- Mean Absolute Error Percentage (MAEP)
- Precipitation Summary Percentage (PSP)
- Precipitation Maximum Percentage (PMP)

$$ME = \frac{1}{N}\sum_{n=1}^{N}(P_m - P_o)_n$$

$$MAE = \frac{1}{N}\sum_{n=1}^{N}(|P_m - P_o|)_n$$

$$\mathrm{MEP} = \frac{\mathrm{ME}}{\frac{1}{\mathrm{N}}\sum_{\mathrm{n=1}}^{\mathrm{N}}(\mathrm{P_o})_\mathrm{n}} \times 100\%$$

$$\mathrm{MAEP} = \frac{\mathrm{MAE}}{\frac{1}{\mathrm{N}}\sum_{\mathrm{n=1}}^{\mathrm{N}}(\mathrm{P_o})_\mathrm{n}} \times 100\%$$

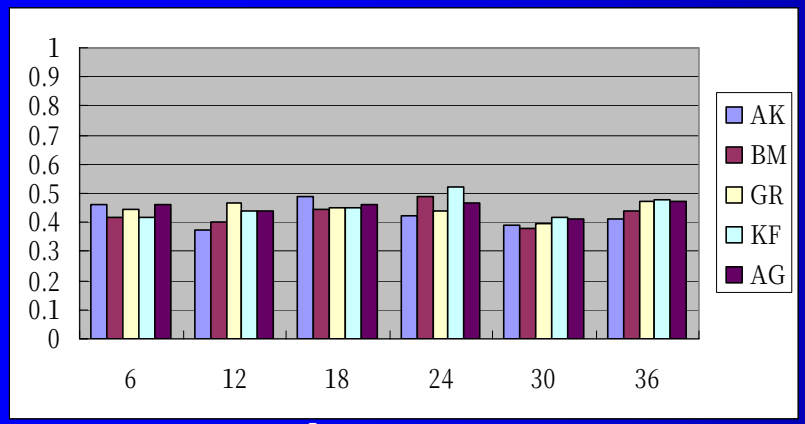
$$PSP = \frac{\sum_{n=1}^{N}(P_{m06} + P_{m12} + P_{m18} + P_{m24} + P_{m30} + P_{m36})_n}{\sum_{n=1}^{N}(P_{o06} + P_{o12} + P_{o18} + P_{o24} + P_{o30} + P_{o36})_n} \times 100\%$$

$$PMP = \frac{P_{M\max}}{P_{O\max}} \times 100\%$$

Cold-air outbreak

Autumn cold front

TS



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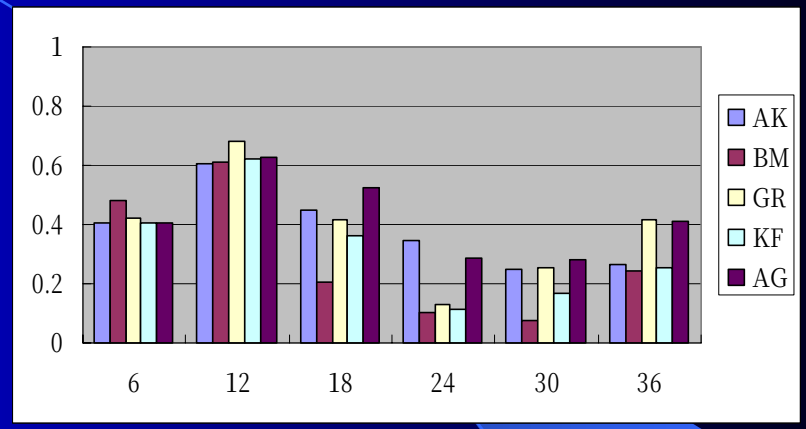

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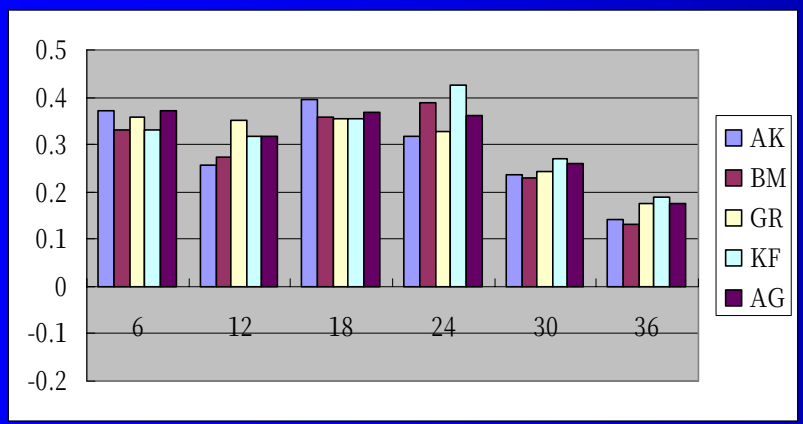
ETS



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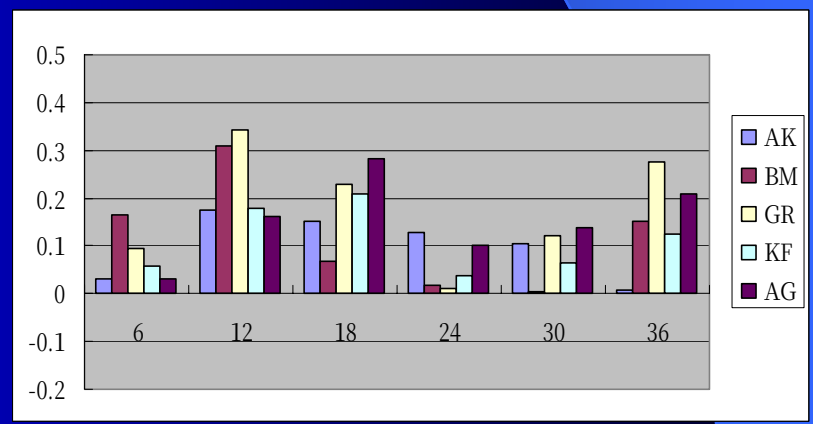


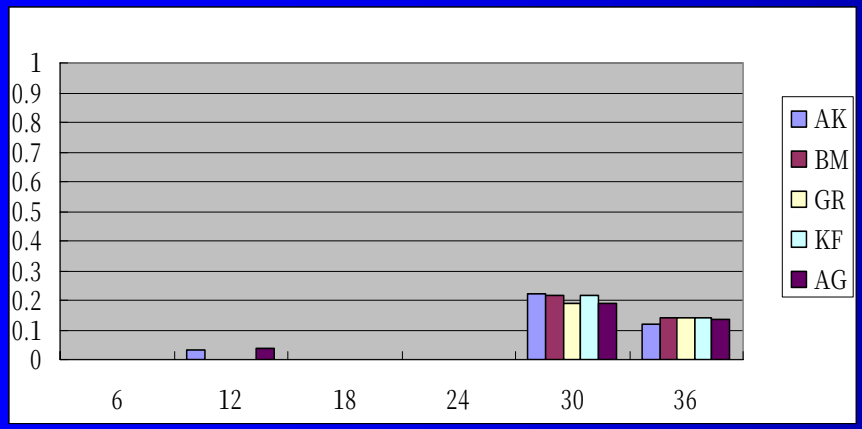
hour

Threshold:0.25 mm

Spring rainfall

Summer thunderstorm

TS



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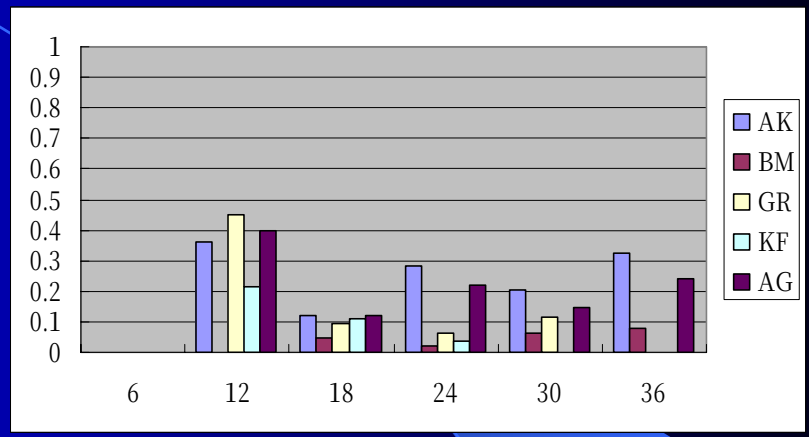

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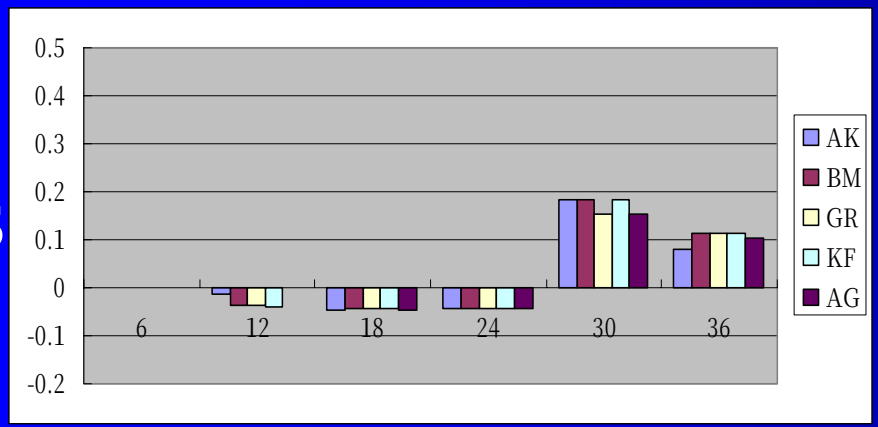
ETS



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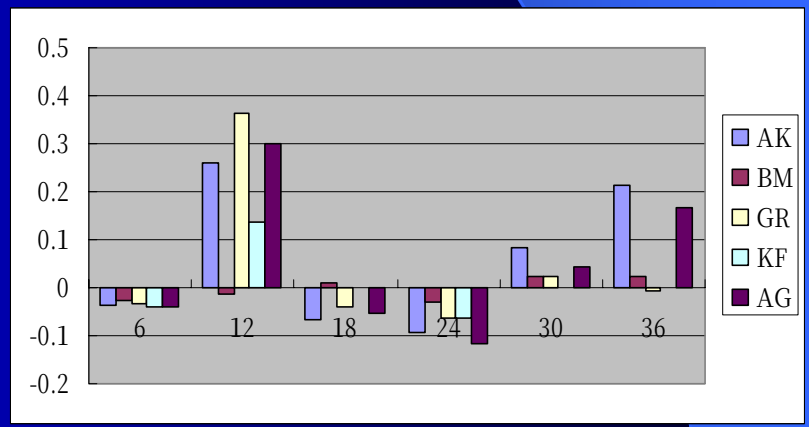


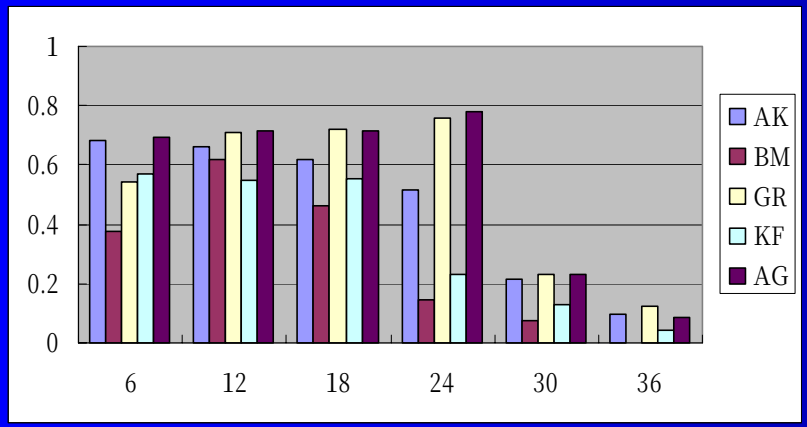
hour

Threshold:0.25 mm

Typhoon Otto

Mei-Yu front

TS



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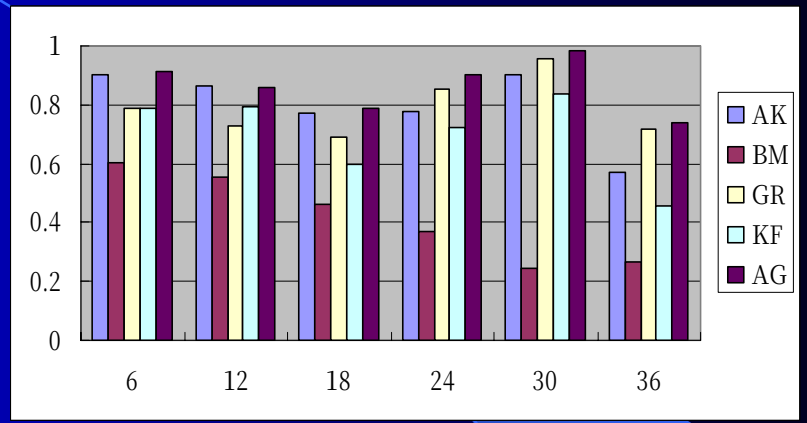

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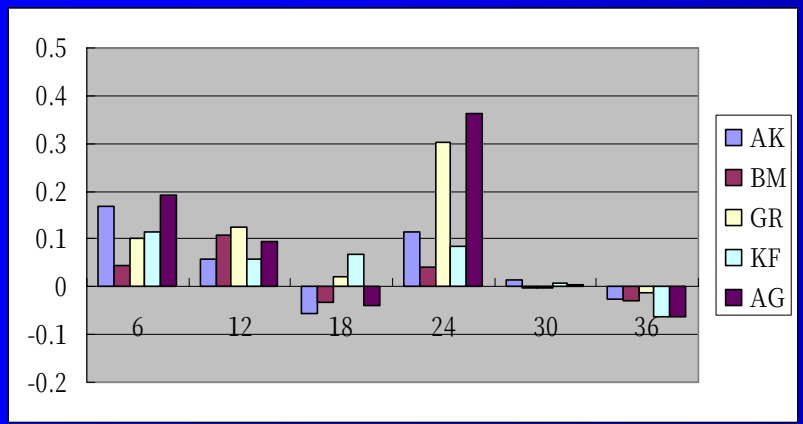
ETS



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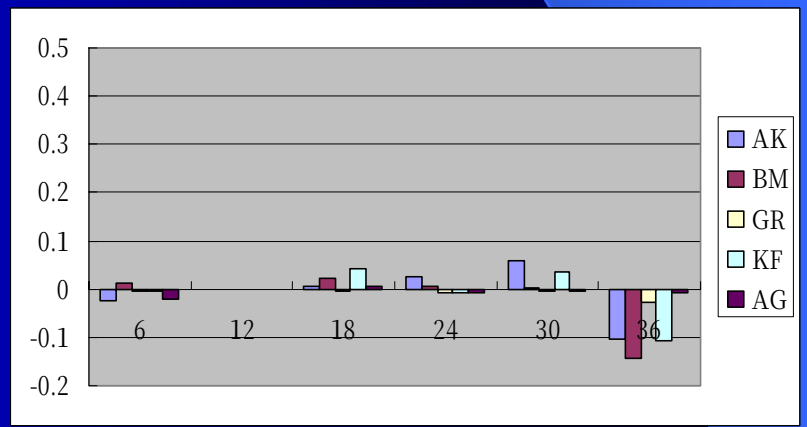


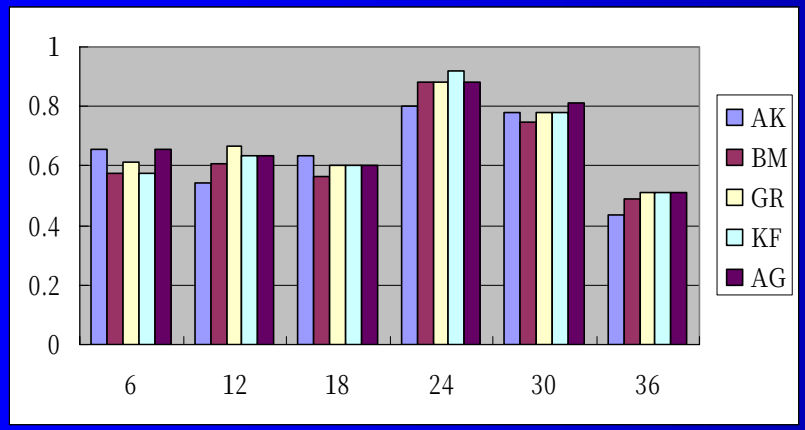
hour

Threshold:0.25 mm

Cold-air outbreak

Autumn cold front

POD



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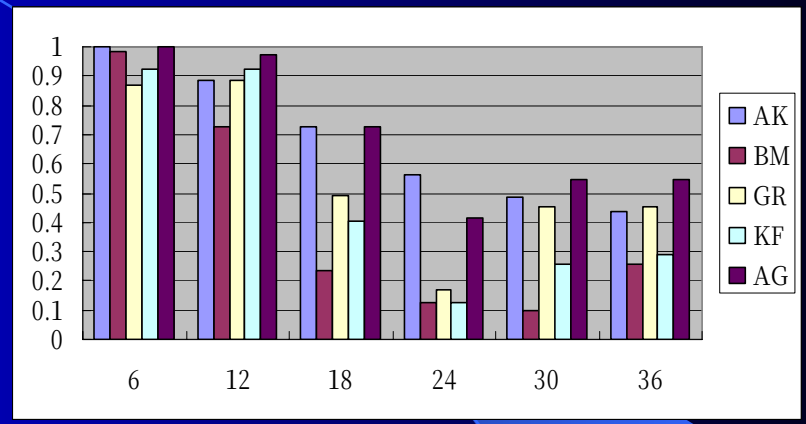
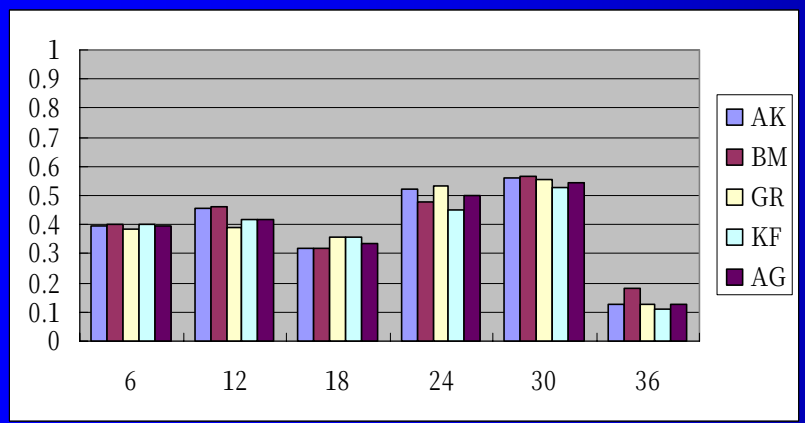


hour

FAR



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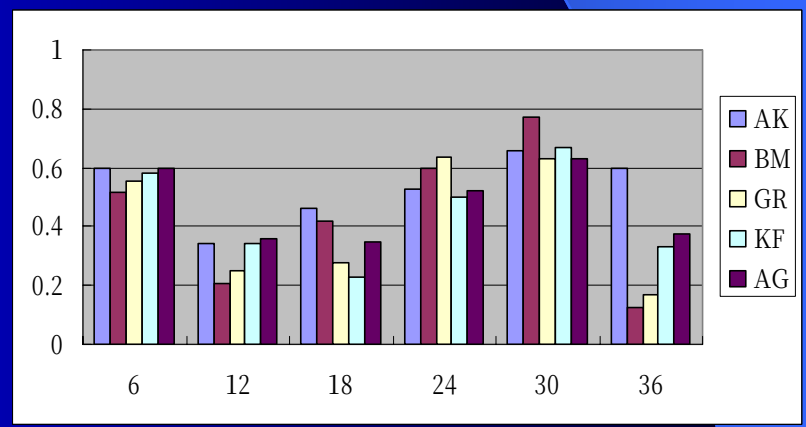


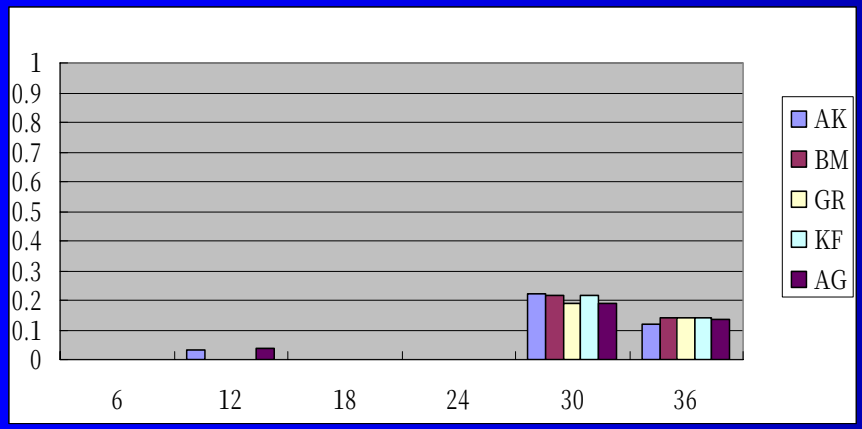
hour

Threshold:0.25 mm

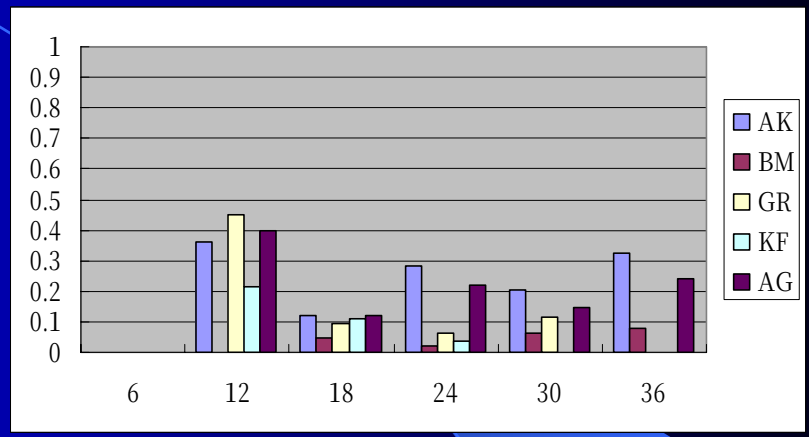
Spring rainfall

Summer thunderstorm

POD



hour



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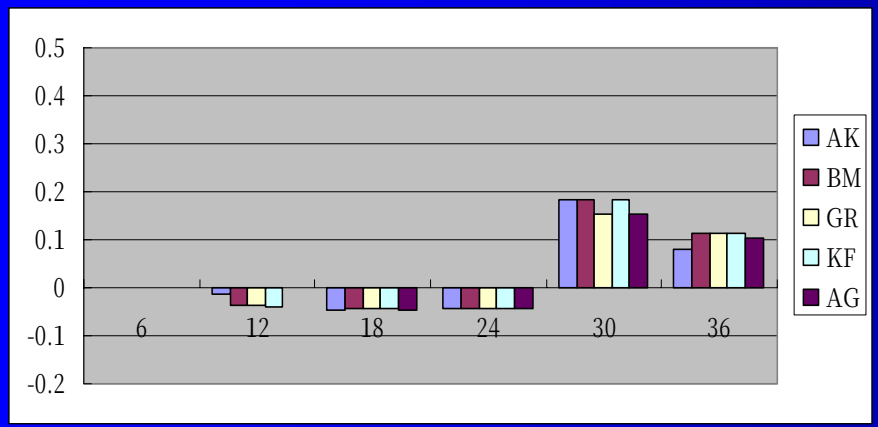
FAR



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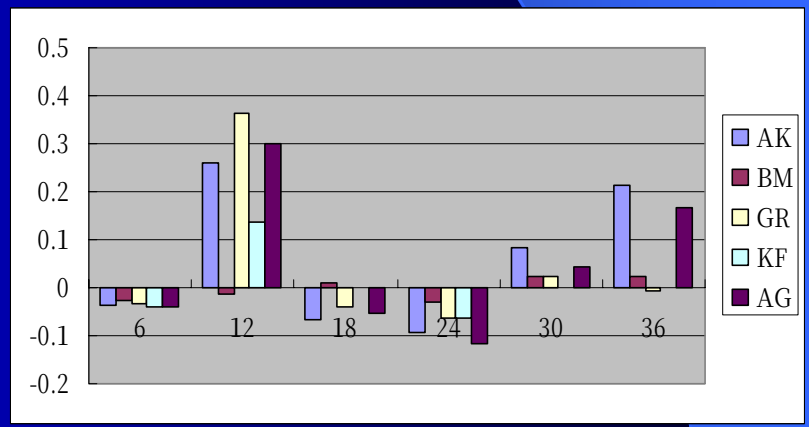


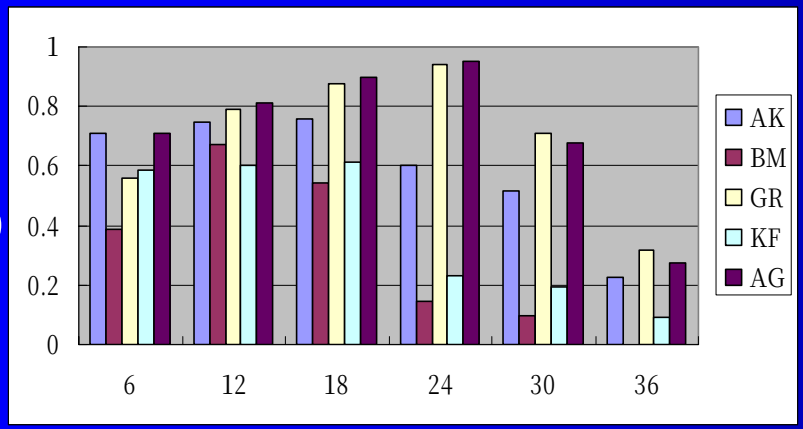
hour

Threshold: 0.25 mm

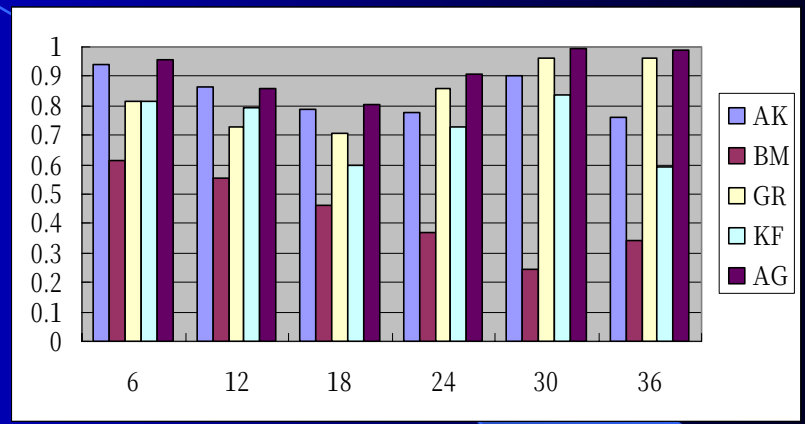
Typhoon Otto

Mei-Yu front

POD

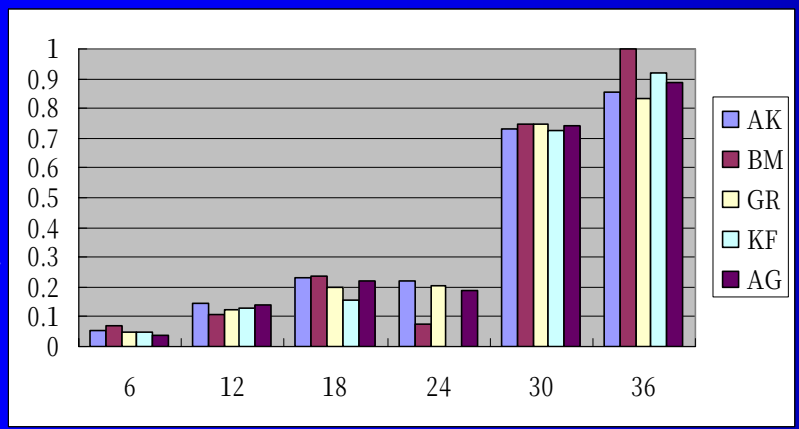


hour

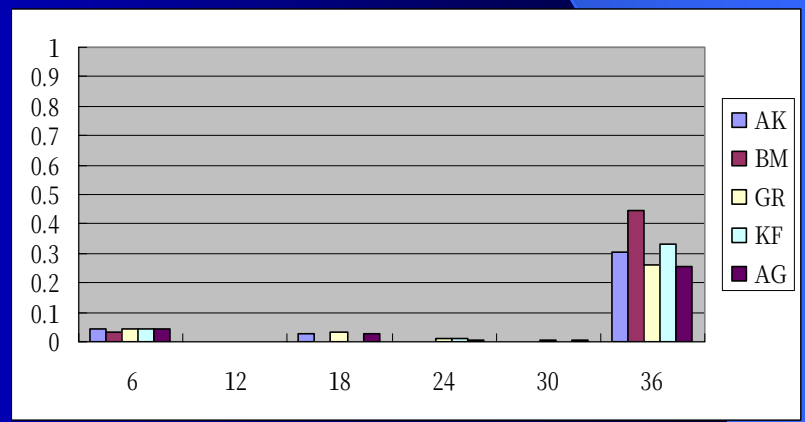


hour

FAR



hour



hour

Threshold:0.25 mm

Mean Relative Error Percentage

Case	AK	BM	GR	KF	AG
Cold-air outbreak	***-35.85#***	-35.12	-33.11#*	-35.72#	-34.97#
Autumn Cold front	-42.86	***-27.59#****	***-34.86***	***-38.10***	***-35.85***
Spring rainfall	441.43	252.03	238.64	259.26	298.04
Summer thunderstorm	-74.95*	-93.90	-84.96	-86.08	-84.97
Cold season	-39.35	-31.35	-33.98	-36.91	-35.40
Warm season	183.24	79.06	76.84*	86.59	106.59
Typhoon Otto	-71.08	-71.85	-41.48*	-85.67	-67.52
Mei-Yu front	-47.80	-80.88	-44.61	-53.49	-56.69

Unit: %

Precipitation Summary Percentage

Case	AK	BM	GR	KF	AG
Cold-air outbreak	***64.15#***	64.88	***66.87****	64.29	65.05
Autumn cold front	57.14	***72.42#****	***65.14***	***61.90***	***64.15***
Spring rainfall	541.32	352.03	***338.76****	359.24	397.84
Summer thunderstorm	***25.06****	6.10	15.05	13.91	15.03
Cold season	60.64	***68.65****	66.01	63.09	64.60
Warm season	283.03	***179.06***	176.90	186.57	206.44
Typhoon Otto	29.25	25.73	***51.49****	13.80	30.07
Mei-Yu front	52.20	19.12	***55.39****	46.52	43.31

Unit: %

Precipitation Maximum Percentage

Case	AK	BM	GR	KF	AG
Cold-air outbreak	***60.63****	58.06	57.16	58.10	***56.79#***
Autumn cold front	25.08	***81.10****	***79.47#***	54.04	47.46
Spring rainfall	***80.54#****	72.46	50.79	***63.26#***	50.32
Summer thunderstorm	24.11	***30.08****	16.86	13.86	19.24
Cold season	42.86	69.58*	***68.32***	56.07	52.12
Warm season	***52.33****	51.63	33.83	38.56	34.78
Typhoon Otto	58.77	***102.09#****	71.33	49.36	61.60
Mei-Yu front	56.96	48.99	54.90	***64.58****	49.97

Unit: %

Summary for rainfall area forecast

- Besides the warm-season events, the MM5 model has good predictive skill for 6-h accumulated rainfall in the Taiwan area.
- For rainfall area and amount predictions, the MM5 model performs better in cold-season events than in warm-season events.
- Besides the warm-season events, the ensemble forecast (AG) has the best skill in predicting the occurrence of rainfall (0.25-mm threshold).
- Each CPS has very different rainfall-forecast performance under different synoptic conditions.

Summary for rainfall amount forecast

- Besides the spring rainfall case, all CPSs underestimate rainfall amount, especially for heavy rainfall cases (Mei-Yu front and typhoon).
- In terms of total rainfall amount, GR has the best forecasts in four out of six cases.
- In terms of rainfall maximum prediction, BM has the best performance in three out of six cases.

Summary

- Besides warm-season events, four CPSs and the ensemble forecasting show generally good skill over the Taiwan area (TS > 0.4).
- None of the CPSs schemes consistently out-performs the others in all measures of forecast skill.
- The MM5 tends to overpredict the area of light rainfall and underpredict the heavy amounts.