UNESCAP/WMO Typhoon Committee

United Nations ESCAP

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Typhoon Committee Roving Seminar 2011

Topic B(2) :

Operational QPE/QPF Systems in Action

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22 September 2011

Petaling Jaya, Malaysia

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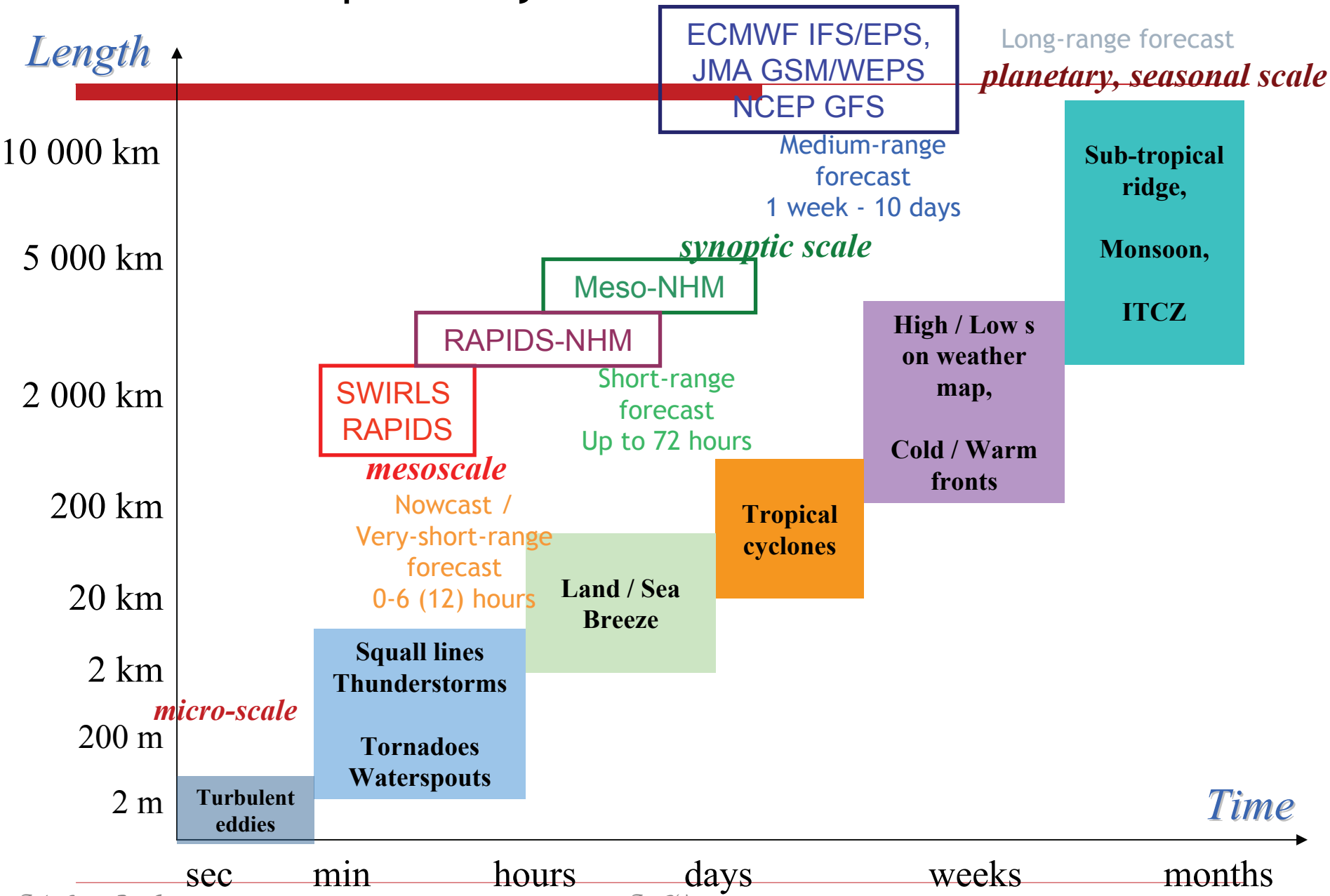
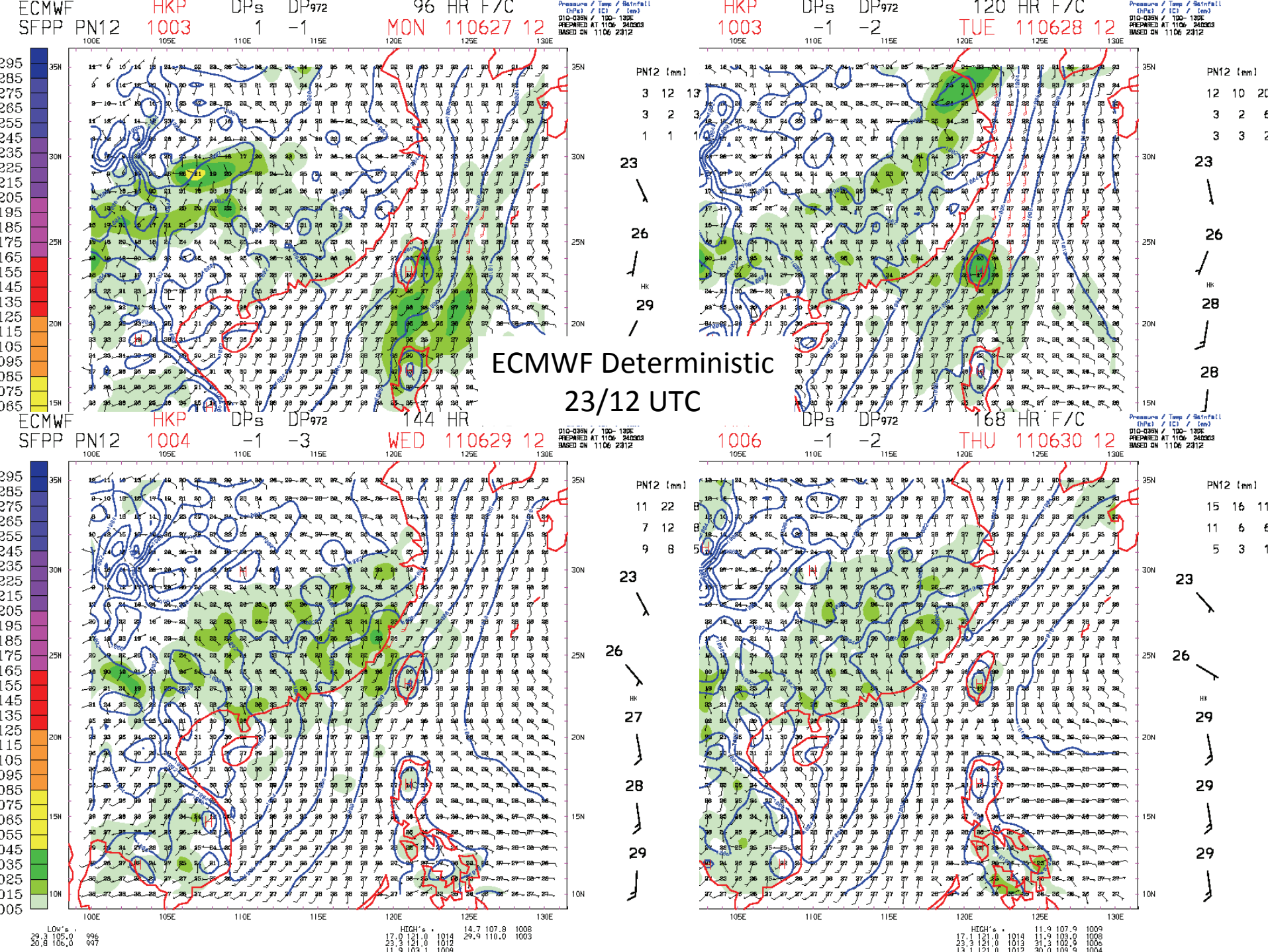
QPE/QPF Tools @HKO

Scales of Atmospheric Systems




ECMWF
SFPP PN12
HKP 1003 DPs 1 DP972 -1
96 HR F/C
MON 110627 12
HKP 1003 DPs -1 DP972 -2
120 HR F/C
TUE 110628 12
ECMWF
SFPP PN12
HKP 1004 DPs -1 DP972 -3
144 HR
WED 110629 12
DPs -1 DP972 -2
168 HR F/C
THU 110630 12
PN12 (mm)
ECMWF Deterministic
23/12 UTC

ECMWF EPSgram 23/12 UTC

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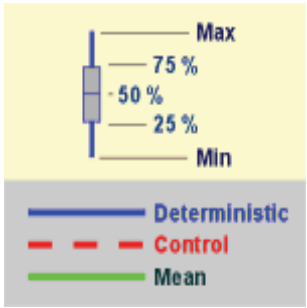
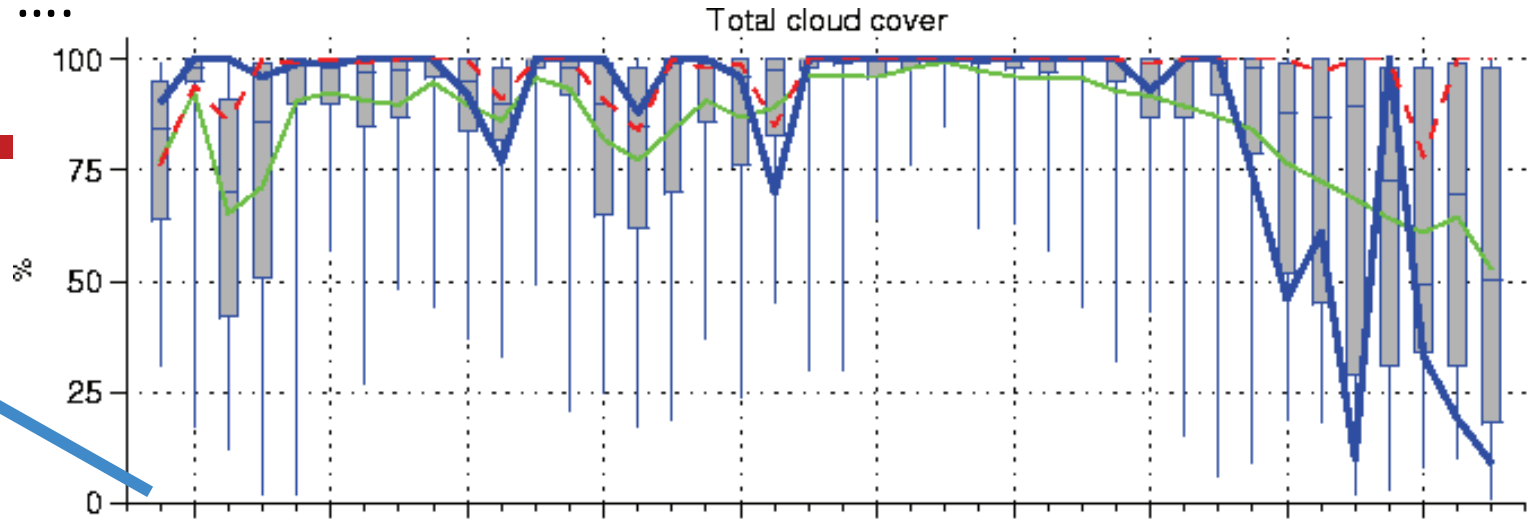
5 days before ….





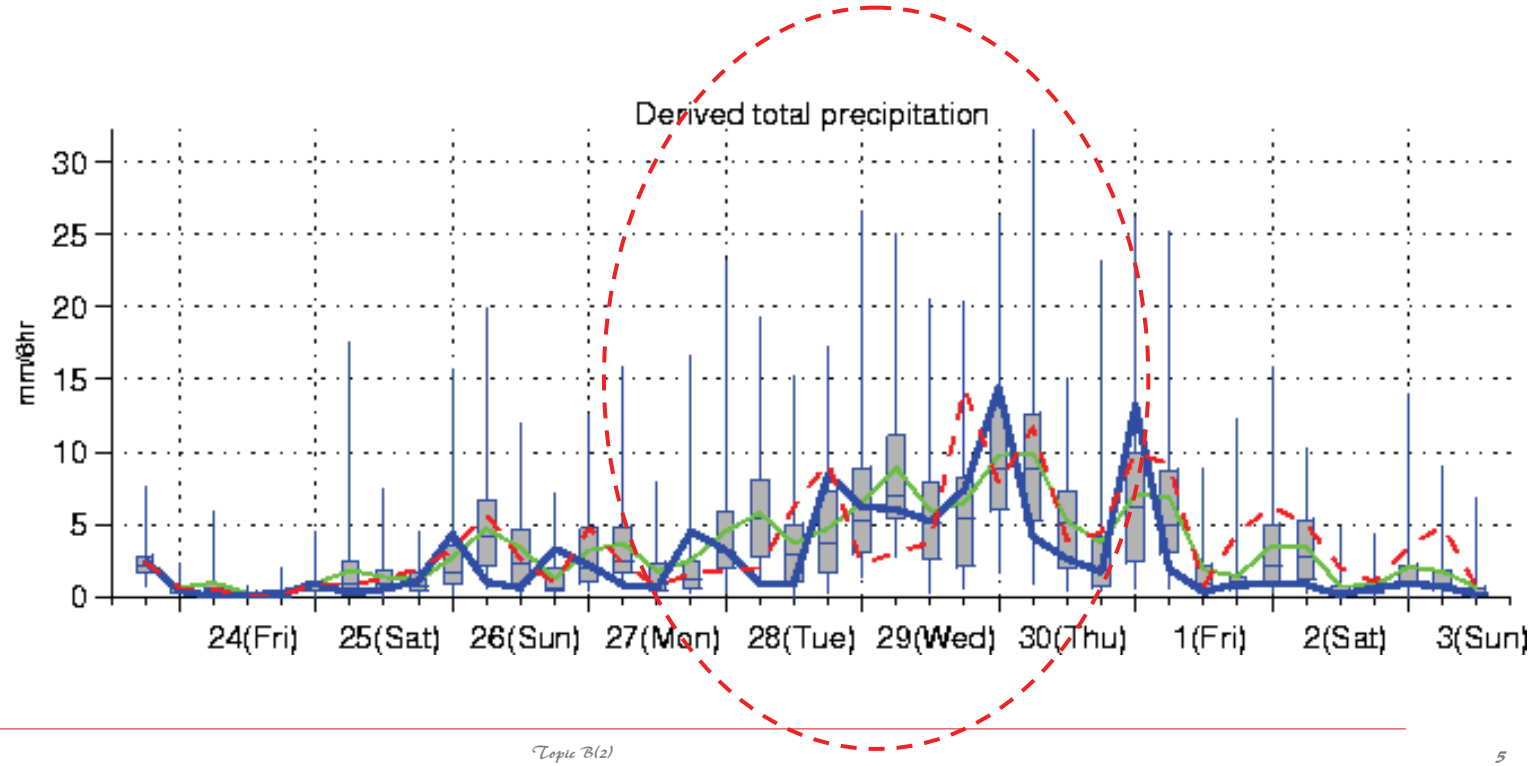


Table 1. Summary of QPF of Global Models for 28 Jun 2011 (TUE)

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Model	Product	Base Time		
		22/12 Z	23/00 Z	23/12 Z
Ensemble	Automatic Forecast	Showers (Moderate)	N/A	A few showers (Light)
JMA	Automatic Forecast	Showers (Moderate)	N/A	A few showers (Light)
	East grid	6 mm	N/A	1 mm
	We			
ECMWF	Au			
	NW			
	SE			
NCEP	Gr			

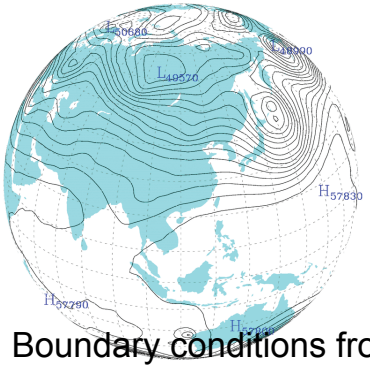
Table 1. Summary of QPF of Global Models for 29 Jun 2011 (WED)

Model	Product	Base Time		
		22/12 Z	23/00 Z	23/12 Z
Ensemble	Automatic Forecast	Showers (Moderate)	N/A	Showers (Moderate)
JMA	Automatic Forecast	A few showers (Light)	N/A	A few showers (Light)
	East grid	3 mm	N/A	1 mm
	West grid	7 mm	N/A	1 mm
ECMWF	Automatic Forecast	Heavy showers (Heavy)	N/A	Showers , heavy at first (Heavy)
	NW grid	30 mm	22 mm	20 mm
	SE			
NCEP	Gr			

Table 1. Summary of QPF of Global Models for 30 Jun 2011 (THU)

Model	Product	Base Time		
		22/12 Z	23/00 Z	23/12 Z
Ensemble	Automatic Forecast	Showers , heavy at first (Heavy)	N/A	Showers (Moderate)
JMA	Automatic Forecast	A few showers (Light)	N/A	Showers (Moderate)
	East grid	6 mm	N/A	7 mm
	West grid	3 mm	N/A	3 mm
ECMWF	Automatic Forecast	Heavy showers (Heavy)	N/A	A few showers, heavy at first (Heavy)
	NW grid	51 mm	37 mm	21 mm
	SE grid	47 mm	59 mm	19 mm
NCEP	Grid Point (22 N,114 E)	N/A	N/A	N/A

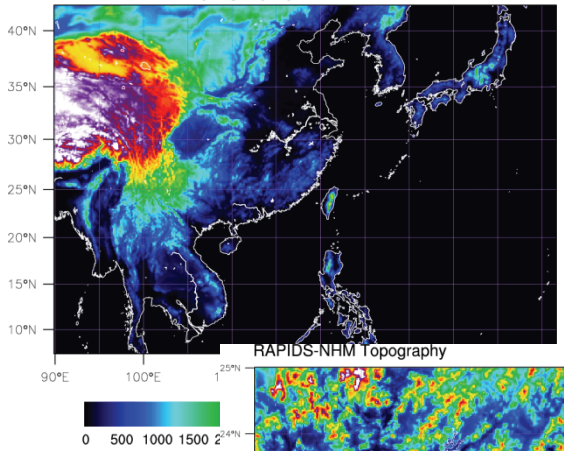
HKO Atmospheric Integrated Rapid cycle (AIR) forecast model system



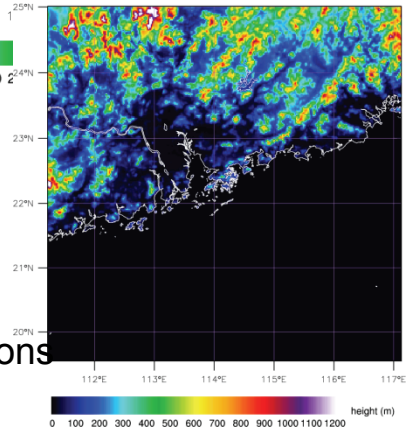
Boundary conditions from JMA GSM

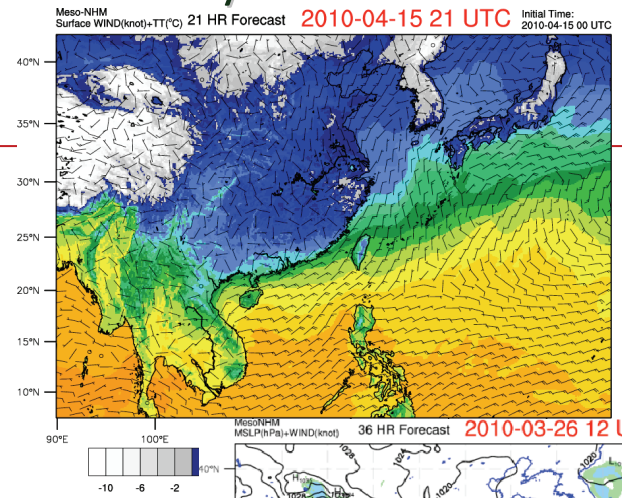
Two regional domains of the Non Hydrostatic Model (JMA-NHM)

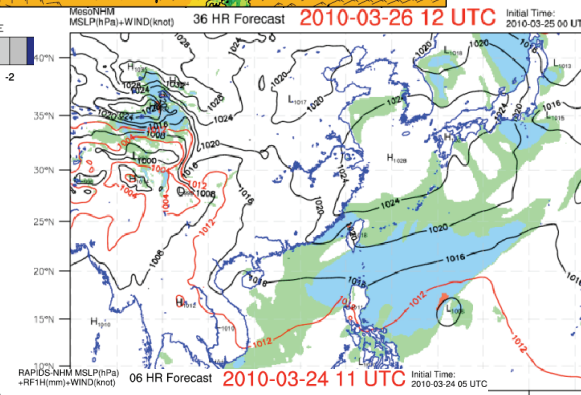
Meso-NHM Topography

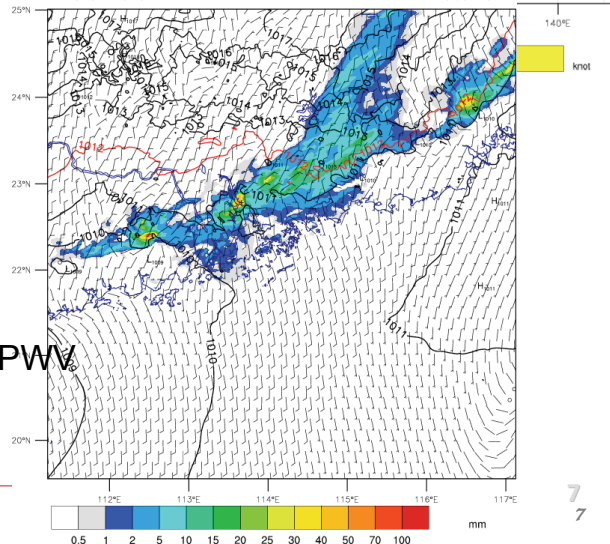


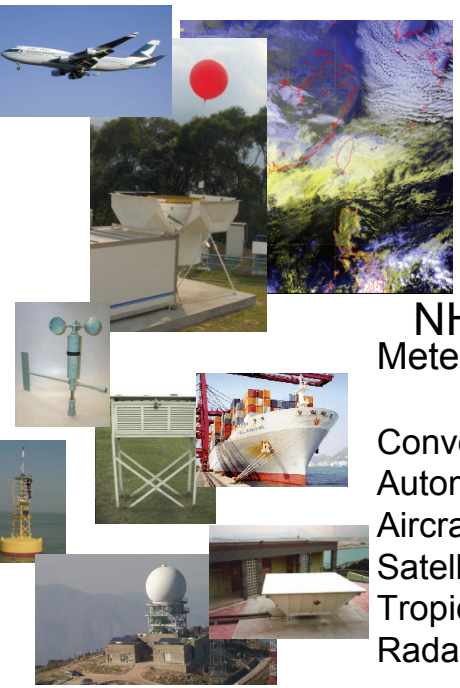
RAPIDS-NHM Topography











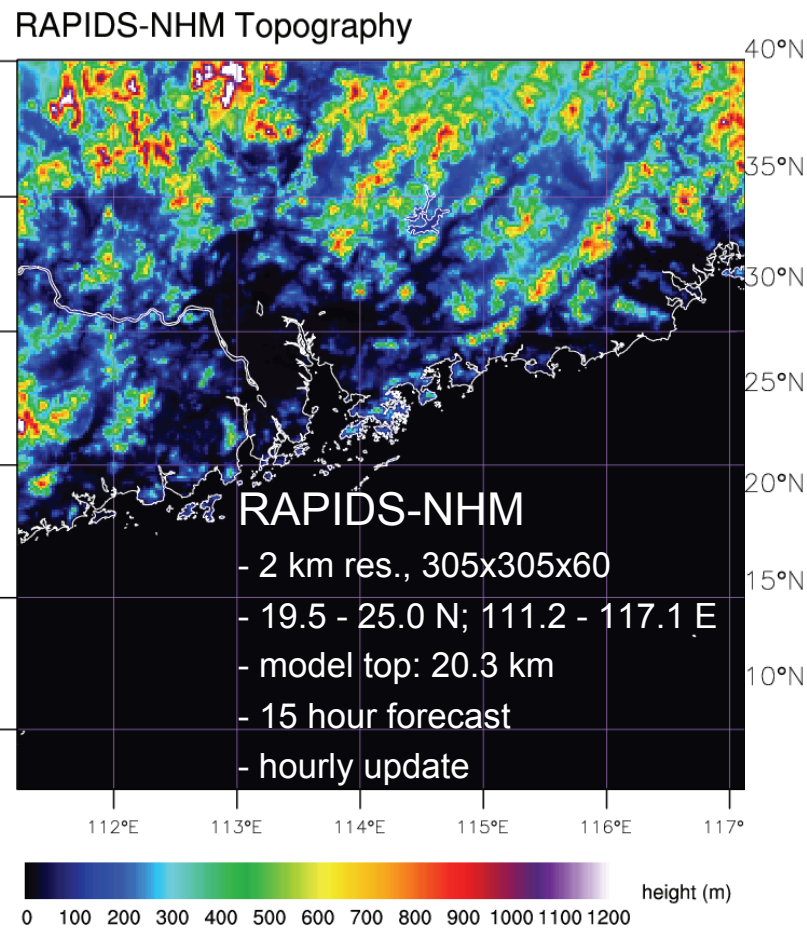
NHM-3DVAR

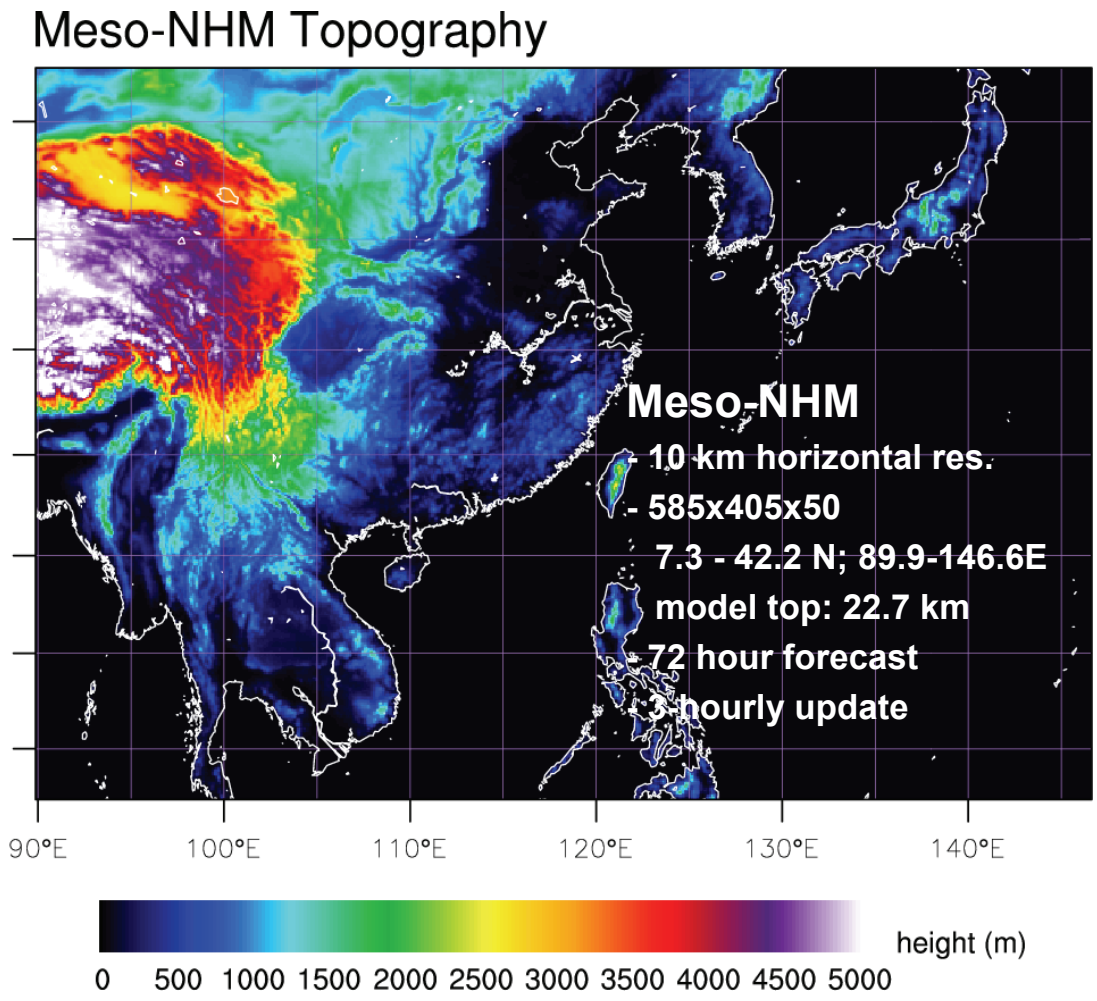
Meteorological Observations

Conventional
Automatic weather stations (HK and Guangdong)
Aircraft
Satellite - cloud motion wind, temperature retrieved profiles, PWV
Tropical cyclone bogus data
Radar – Doppler velocity and radar retrieval wind

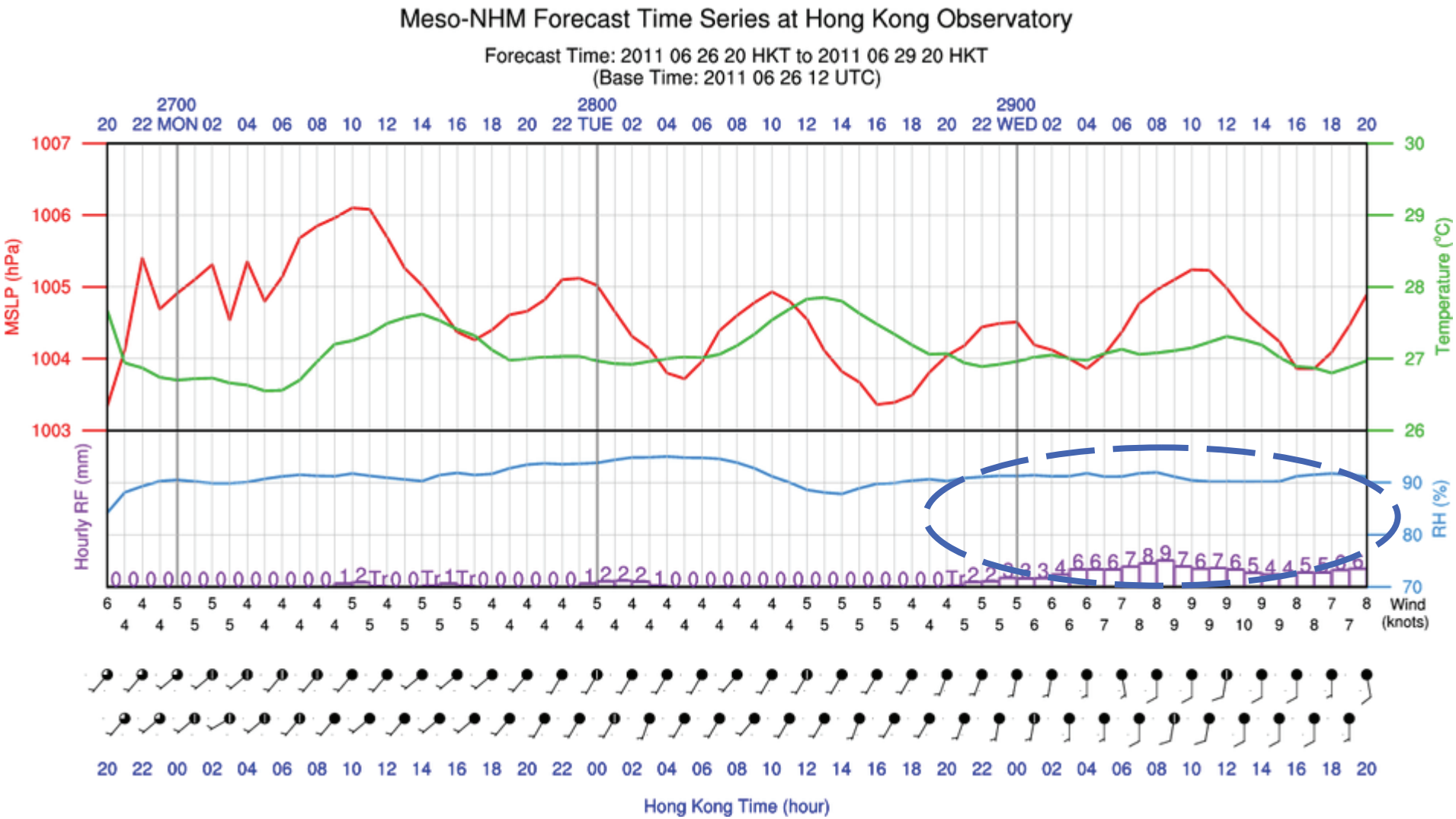
Two NHM domains in AIR Forecast Model System

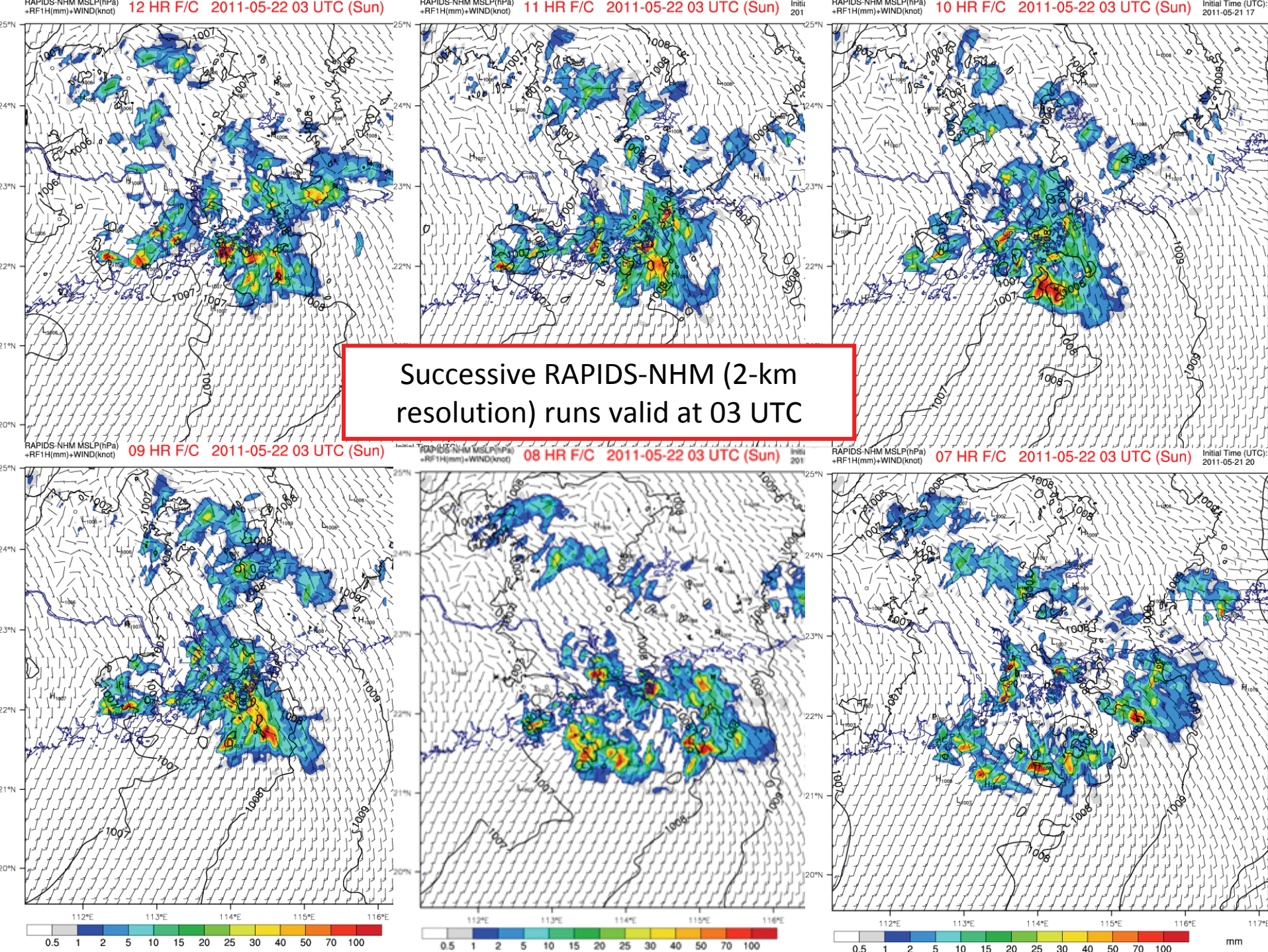
- *Meso-NHM*
- *RAPIDS-NHM*





QPF from Meso-NHM (10 km)

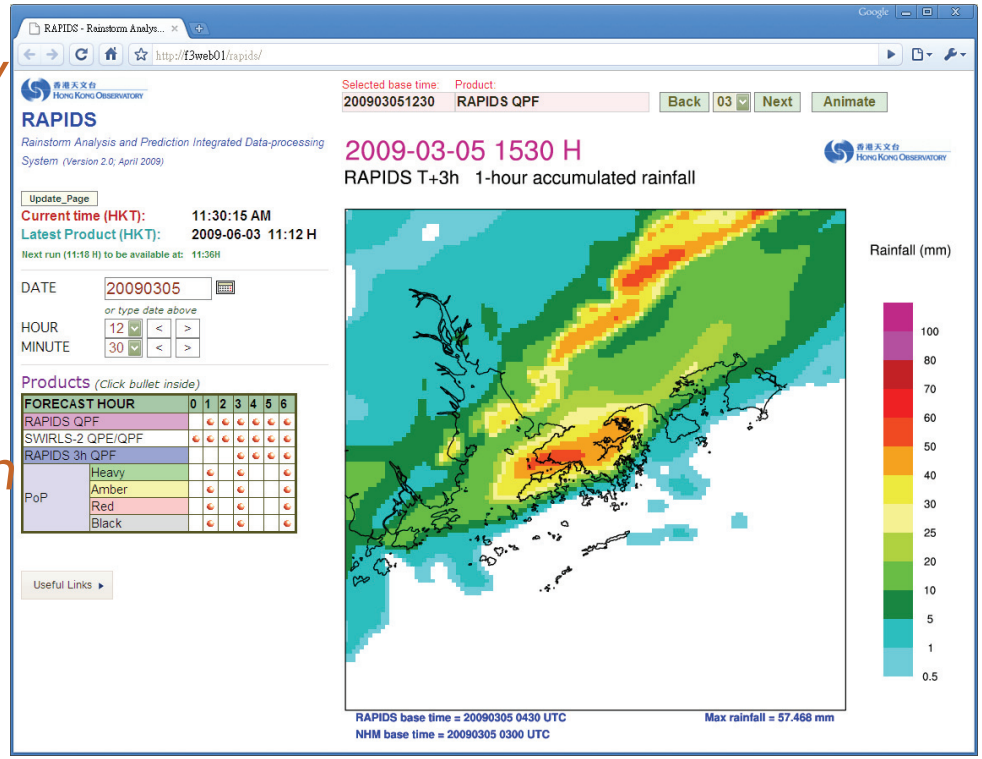


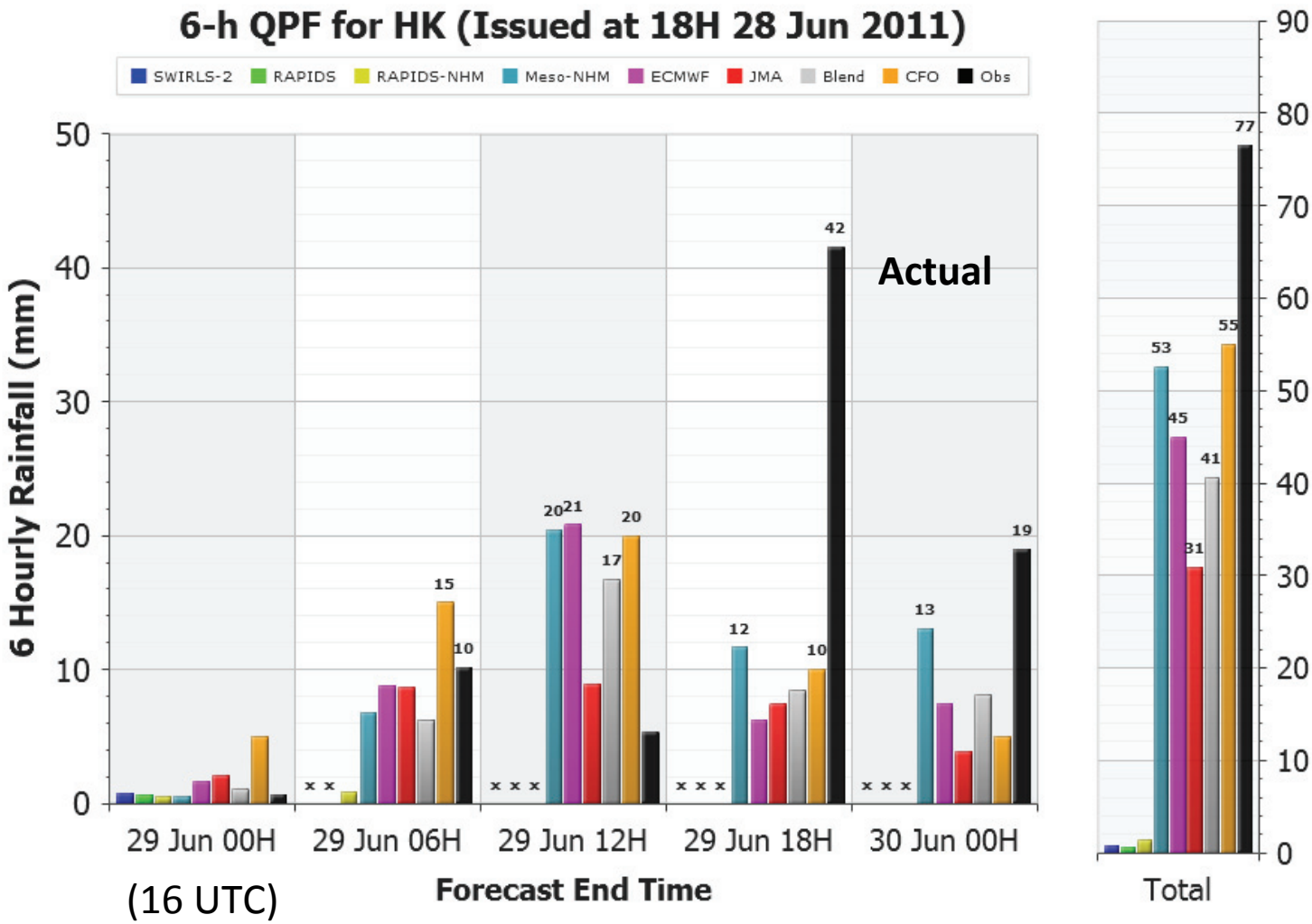


Successive RAPIDS-NHM (2-km resolution) runs valid at 03 UTC

Blended Rainfall Forecast

- **RAPIDS-1**
  - *trial operation since May 2005*
  - *"smart" weighted means of SWIRLS & NWP QPF*
  - *phase correction + intensity calibration on NWP QPF*
  - *6-min updating*
- **RAPIDS-2**
  - *SWIRLS-2 & 2-km NHM*
  - *to launch in 2011*





5-day mean/max (6 hourly rainfall,1991-2010)

	29 Jun 00H	29 Jun 06H	29 Jun 12H	29 Jun 18H	30 Jun 00H
5-Day Mean	2.5	2.6	4.6	3.6	2.2
5-Day Max	48.8	34.7	56.2	67.2	48.8

Nowcasting Support

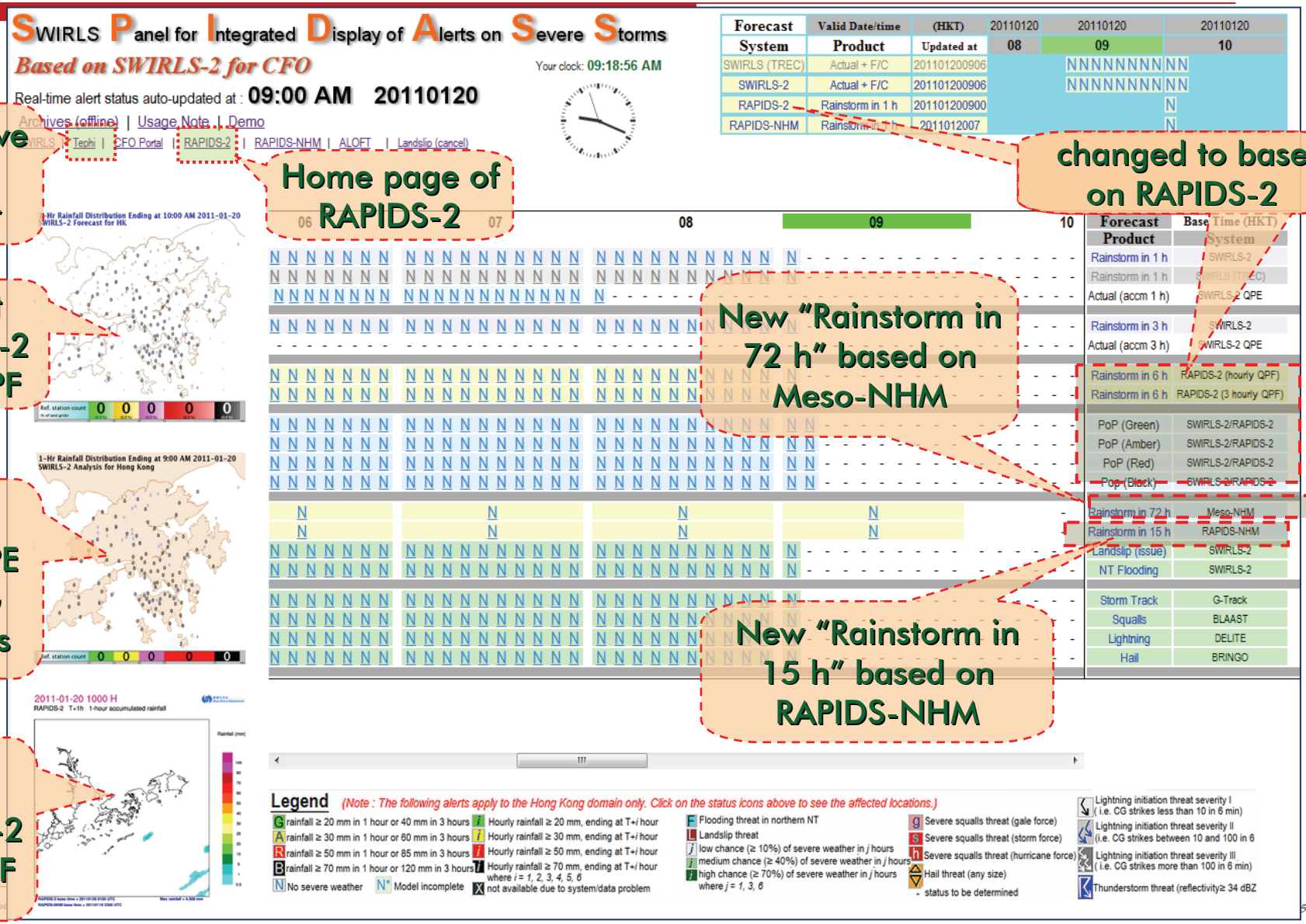
- **SWIRLS Panel**
  - *radar-based ⇒ motion field, rainfall maps, rainstorm alerts and related severe weather*
  - *workstation in CFO (see live demo)*
- **Rainstorm Viewer**
  - *raingauge + SWIRLS ⇒ probability of rainstorm conditioned on current rainfall distribution*
  - *web page on Wx. Info. portal (see live demo)*
- **RAPIDS**
  - *SWIRLS + NHM ⇒ blended QPF, rainstorm alerts, probability of precip*
  - *web page on Wx. Info. + SPIDASS*

Nowcasting Tools

(cont'd)

- **SPIDASS**
  - *SWIRLS Panel for Integrated Display of Alerts of Severe Storms ⇒ one-page summary + r/f maps*
  - *web page on Wx. Info.*
  - *see next section and live demo*
- **Tephi Viewer**
  - *interactive tephigram, latest and time series of instability indices, multi-inputs*
- **SWIRLS-2 Portal for CFO**
  - *one-stop shop for all existing nowcasting products*
  - *6-hr'ly QPF, Interactive Tephi, Lightning Prob., R/G data QC, co-Kriging QPE, etc.*

SPDDASS - Main features



SPIDASS - Use & Interpretation

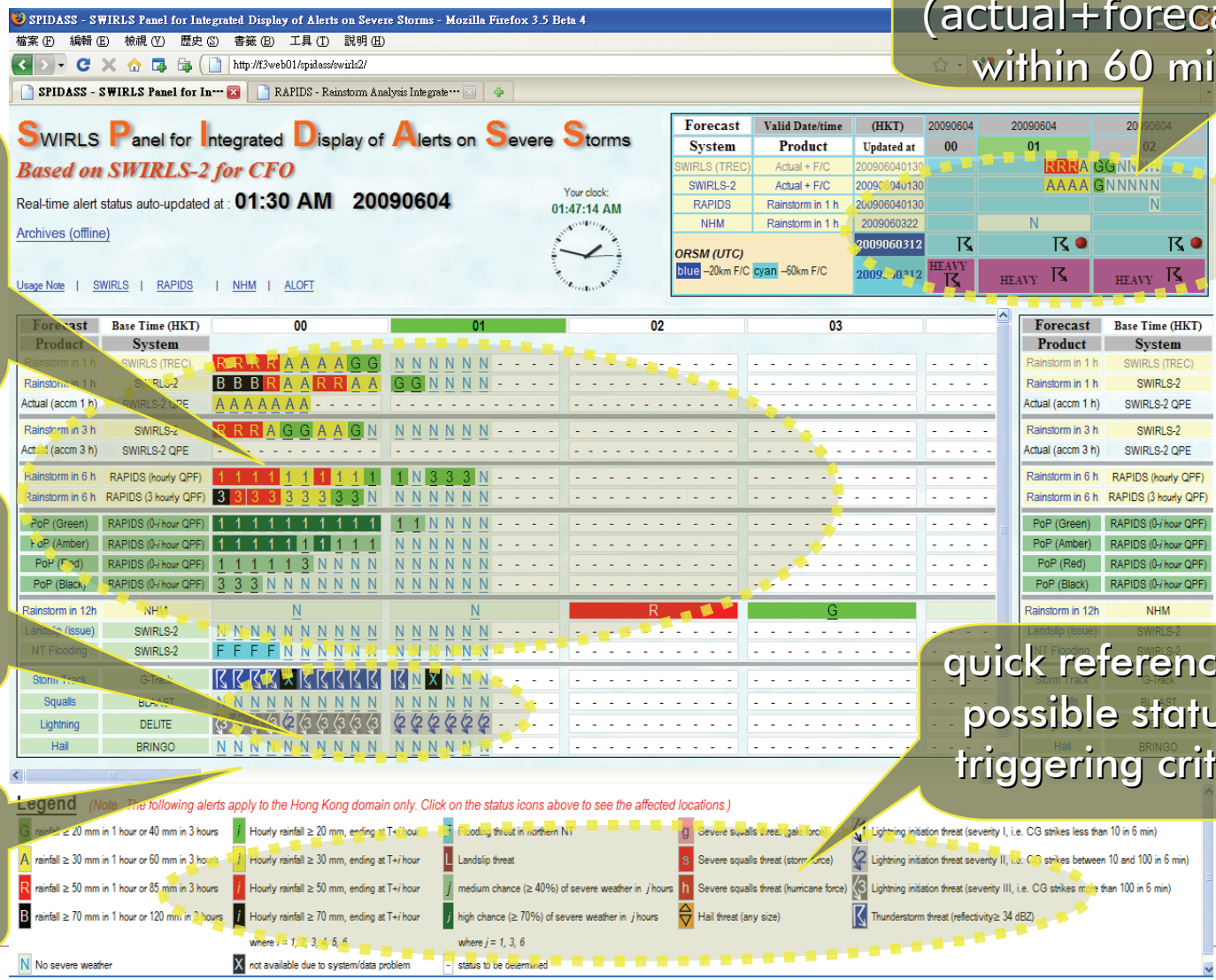
Rainstorm alerts (actual+forecast) within 60 min

Rainstorm-related alerts:
- 1-6 hours
- auto-updated every 6 min

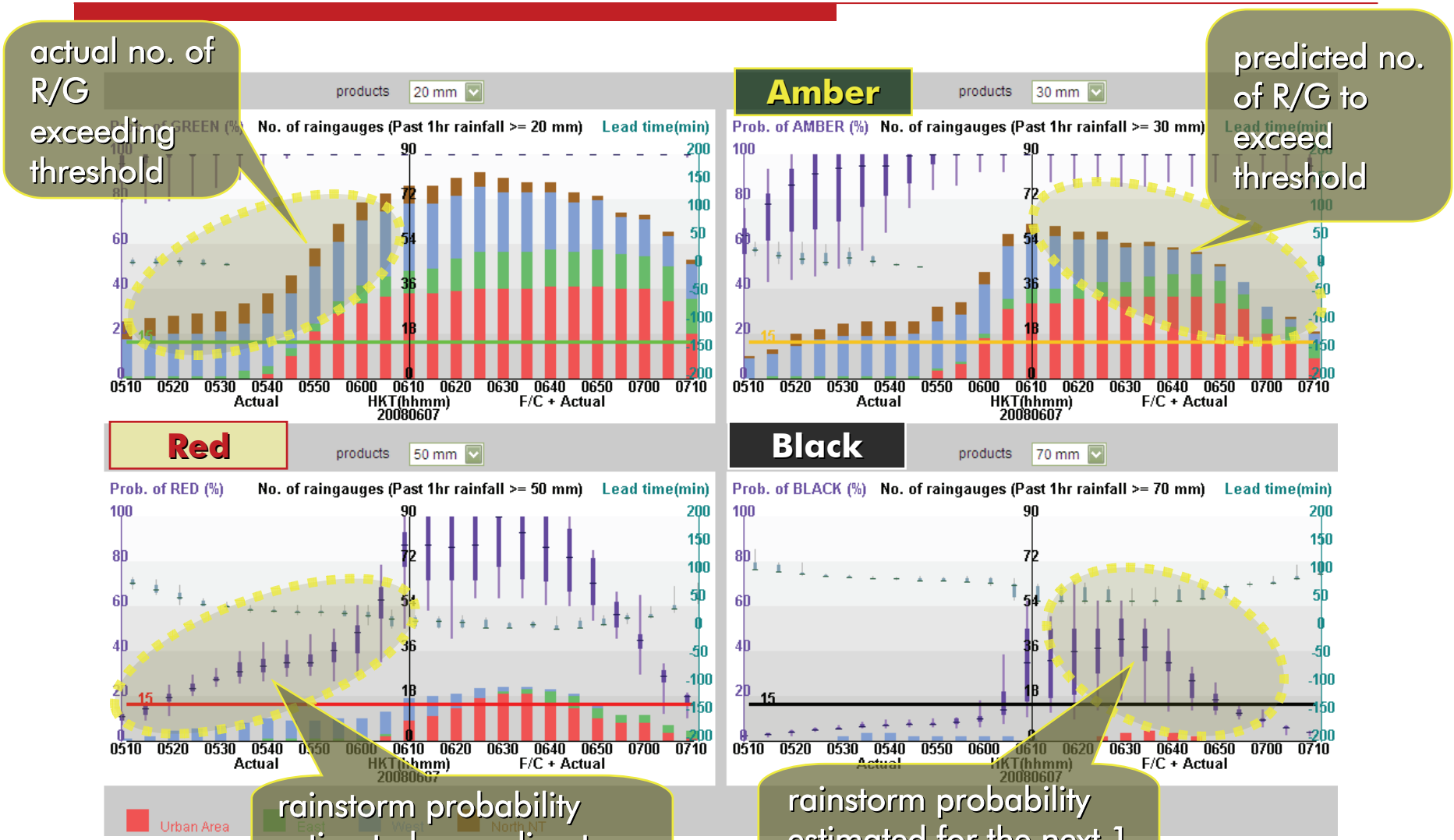
Severe weather alerts associated with thunderstorms

Severe weather map available on mouse click

quick reference on possible status & triggering criteria



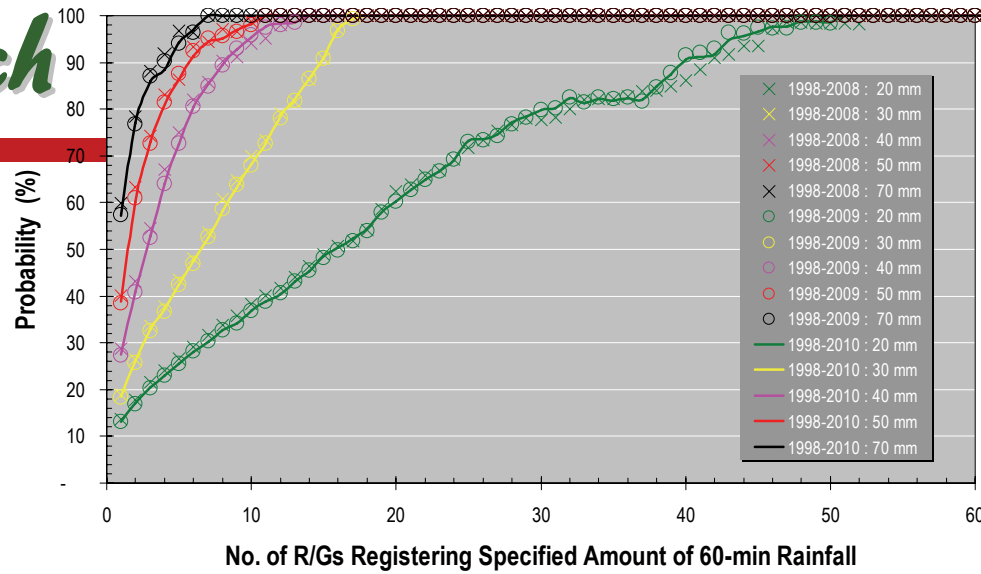
Rainstorm Probability Nowcast



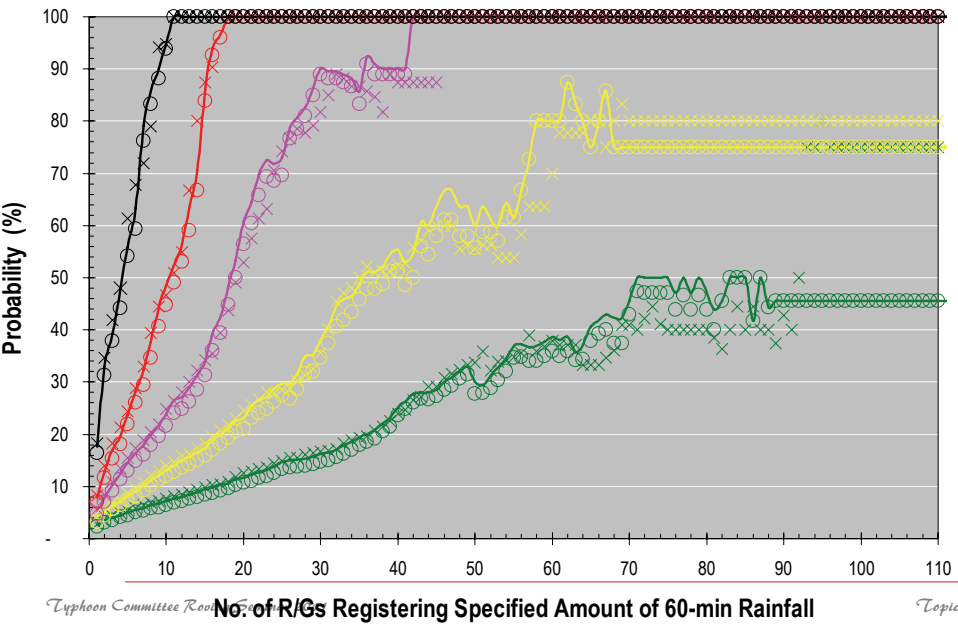
Statistical Approach

- underlying statistics for generating conditional probabilities based on R/G data from 1998-2010

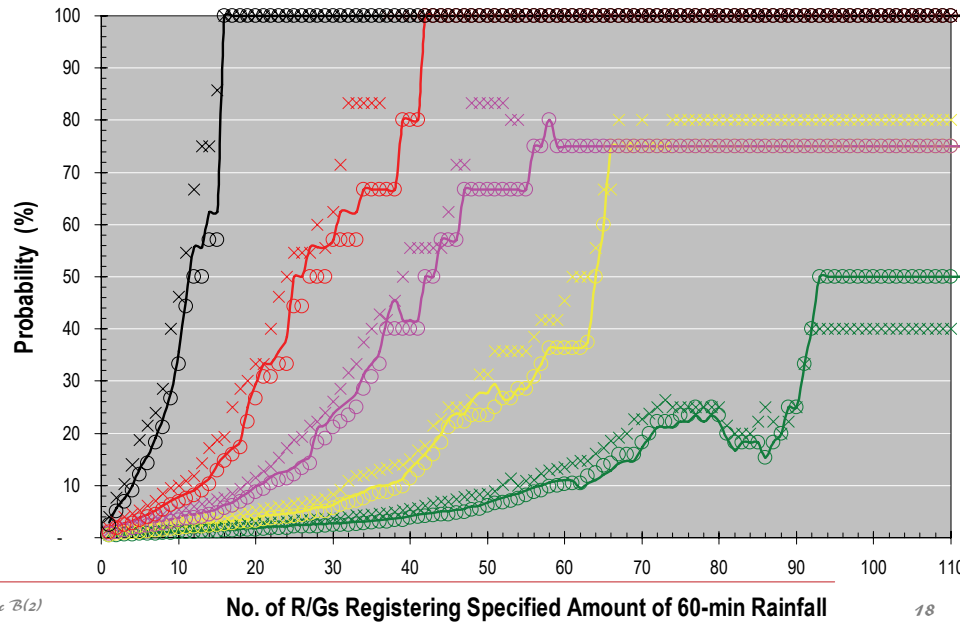
Probability of Amber Rainstorm Warning Conditioned on 60-min Rainfall Distribution



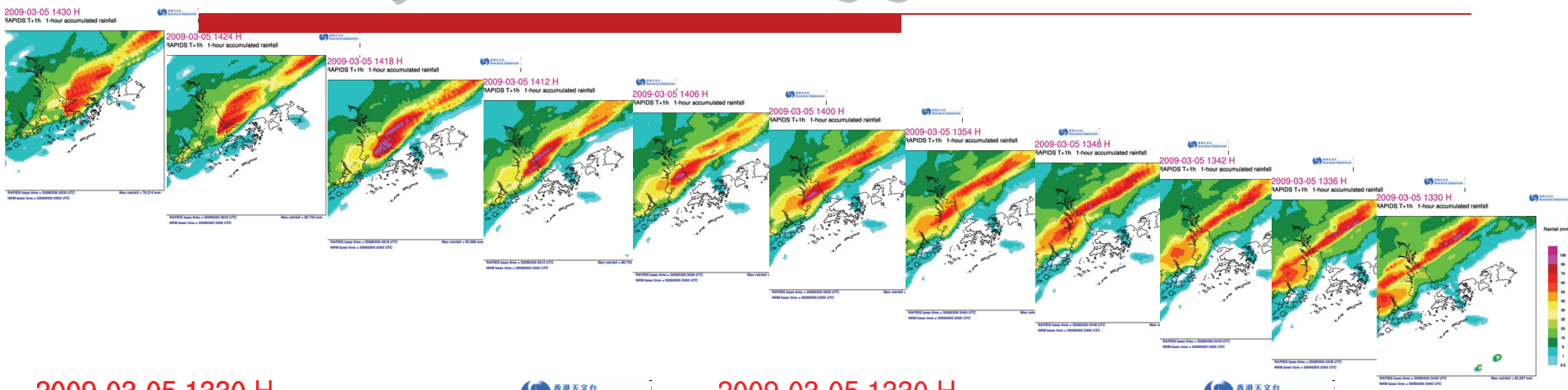
Probability of Red Rainstorm Warning Conditioned on 60-min Rainfall Distribution

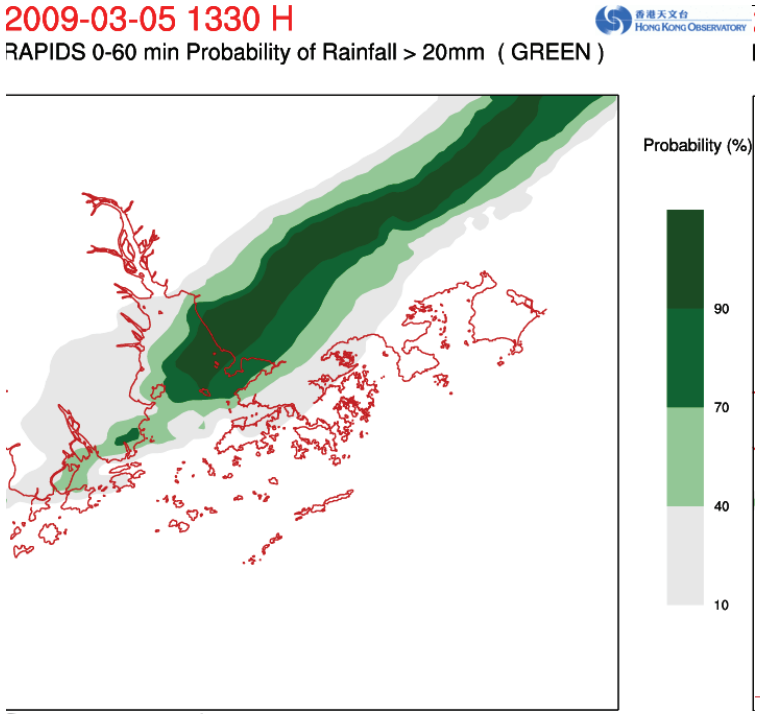


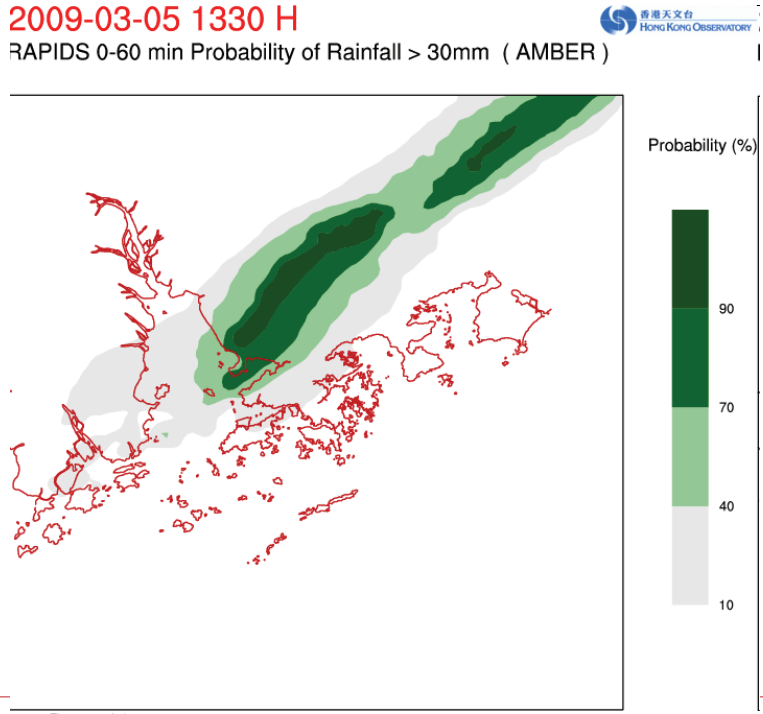
Probability of Black Rainstorm Warning Conditioned on 60-min Rainfall Distribution



PoP by Time-lagged Ensemble







Aggregate latest 10 RAPIDS QPF according to exponential decreasing weights

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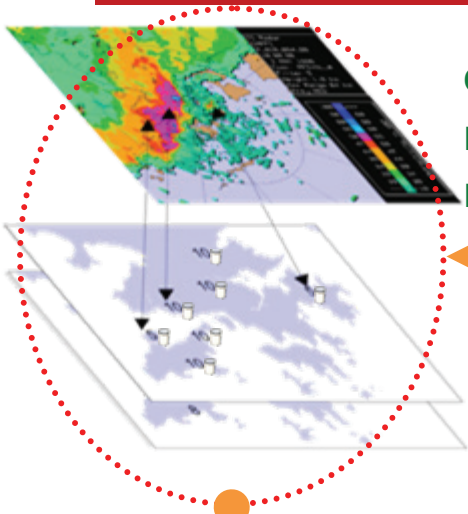
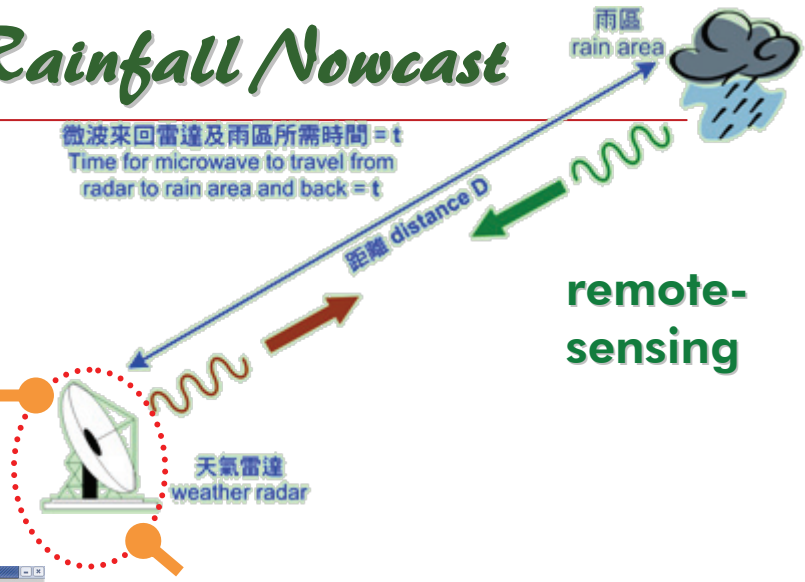
Rainfall Nowcasting Basics

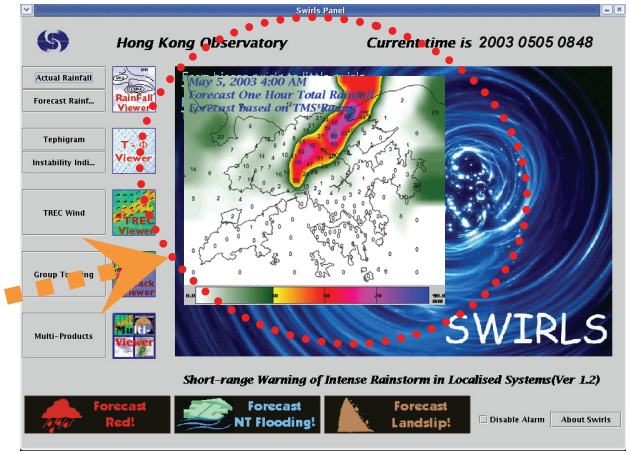
Basic Principles in Radar-based Rainfall Nowcast



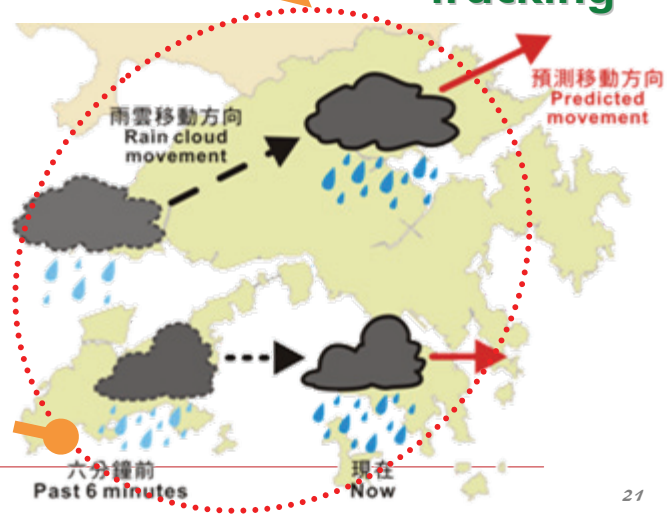
dynamic
radar-raingauge
rainfall calibration

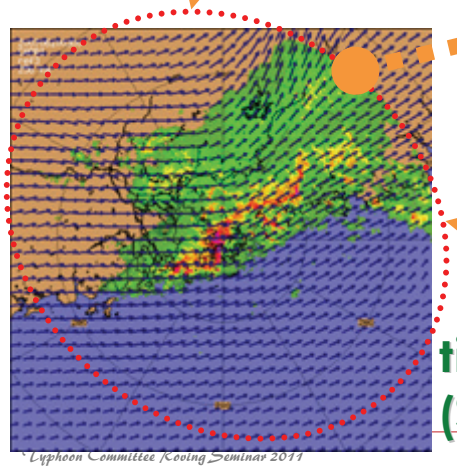


remote-
sensing



storm
tracking





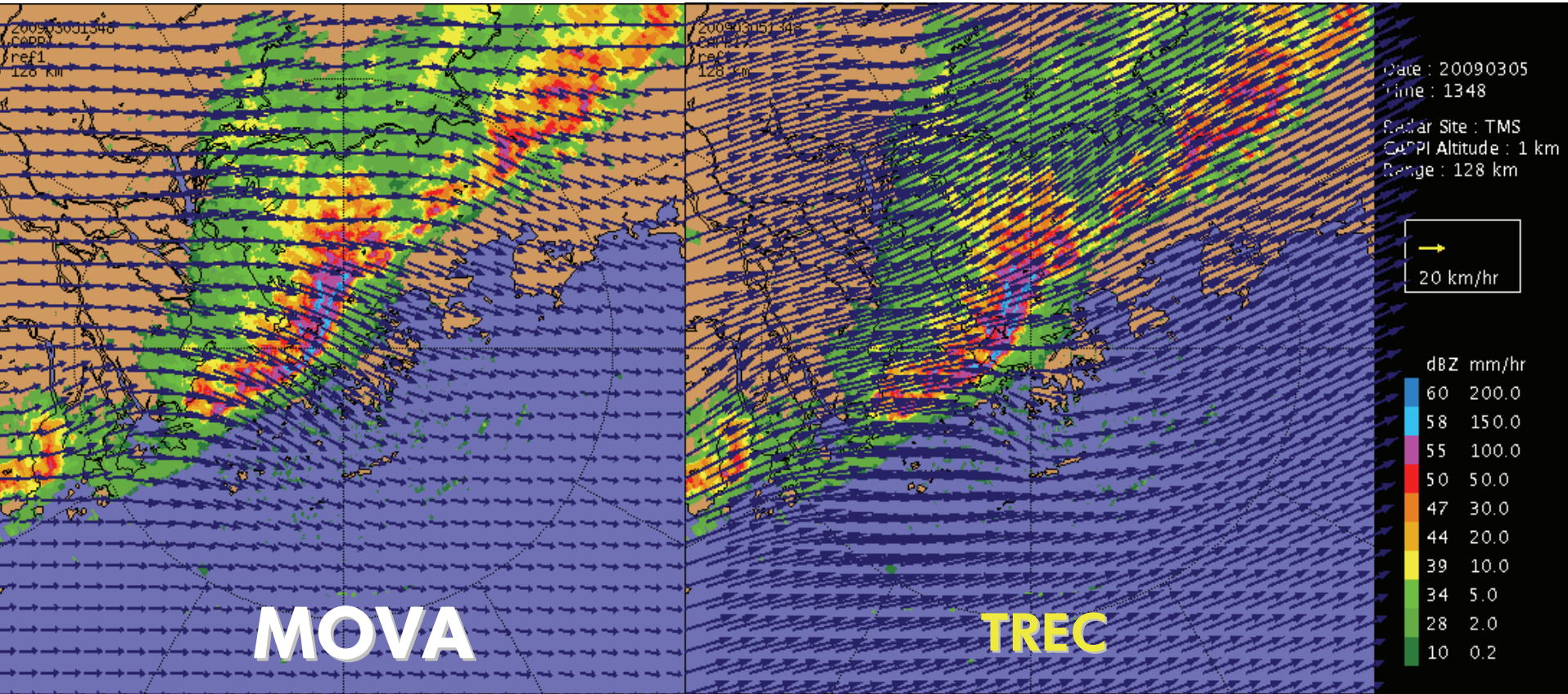
time integration
(Semi-Lagrangian advection)

Steps in Rainfall Nowcast

- **Quantitative Precipitation Estimation**
  - *Real-time dynamic calibration of radar reflectivity using raingauge data*
- **Storm Motion Field Estimation**
  - *TREC*
  - *MOVA*
- **Extrapolation in Time**
  - *Non-linear extrapolation by Semi-Lagrangian advection of reflectivity*
- **Rainfall Accumulation**
  - *Forecast 1, 2,… up to 6 hr accumulated rainfall*

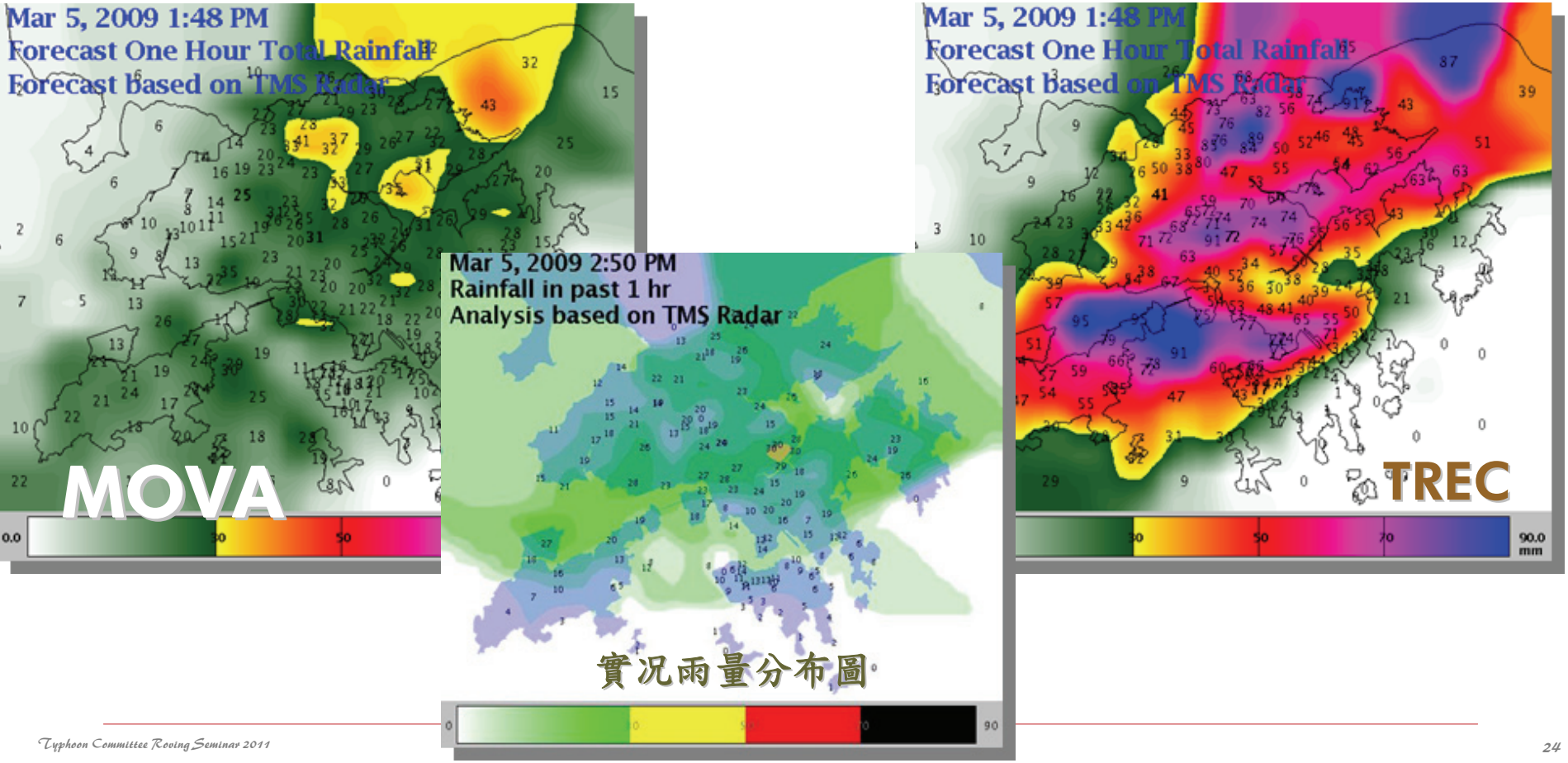
Radar Tracking Example

- squall line on 5 March 2009
  - *MOVA vectors vs TREC winds*
    - optical-flow vs correlation-based tracking



"MOVA" QPF Example

- squall line on 5 March 2009
  - *1-hr MOVA & TREC QPFs vs actual rainfall distribution*



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Quantitative Precipitation Estimation

Basic Principle

In rain, radar measures reflectivity, which is the sixth moment of drop size distribution:

$$Z = \int_0^\infty N(D) D^6 dD$$

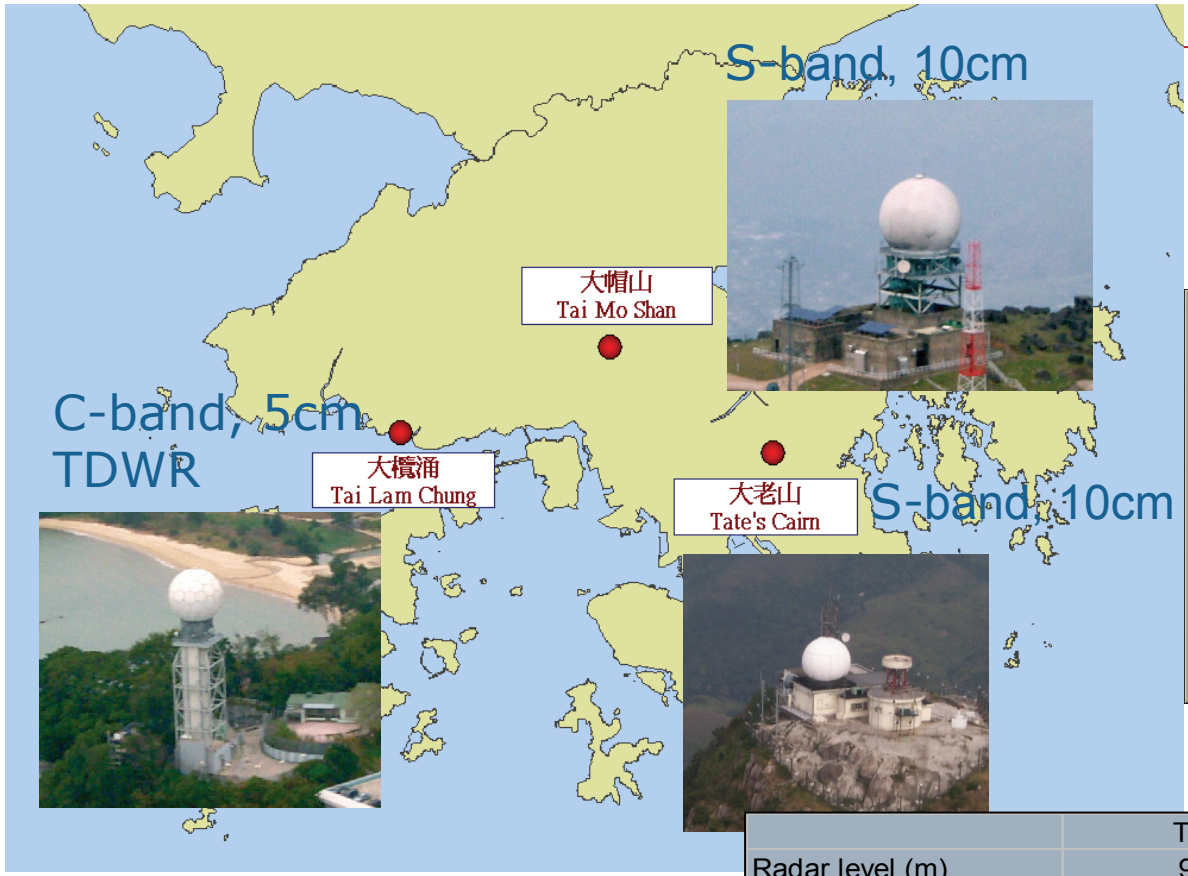
While rain rate is given by:

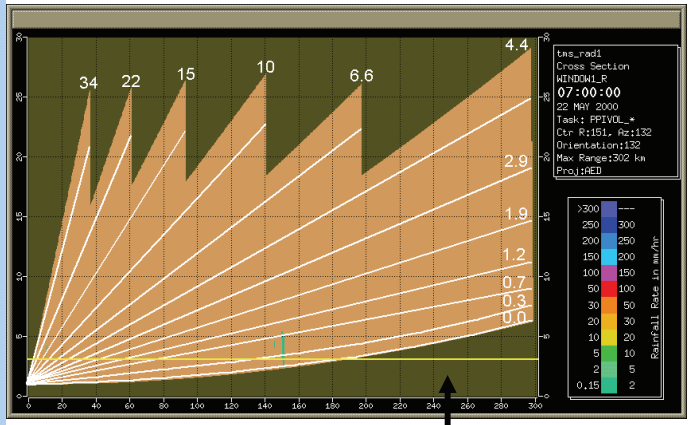
$$R = c \int_0^\infty N(D) V(D) D^3 dD$$

Thus, if we know the DSD with enough accuracy a relationship between *Z* and *R* can be established.
Experience shows that a power law is a good approximation to this relationship: $Z = aR^b$

source: Prof. I. Zawadzki

Doppler Wx Radars

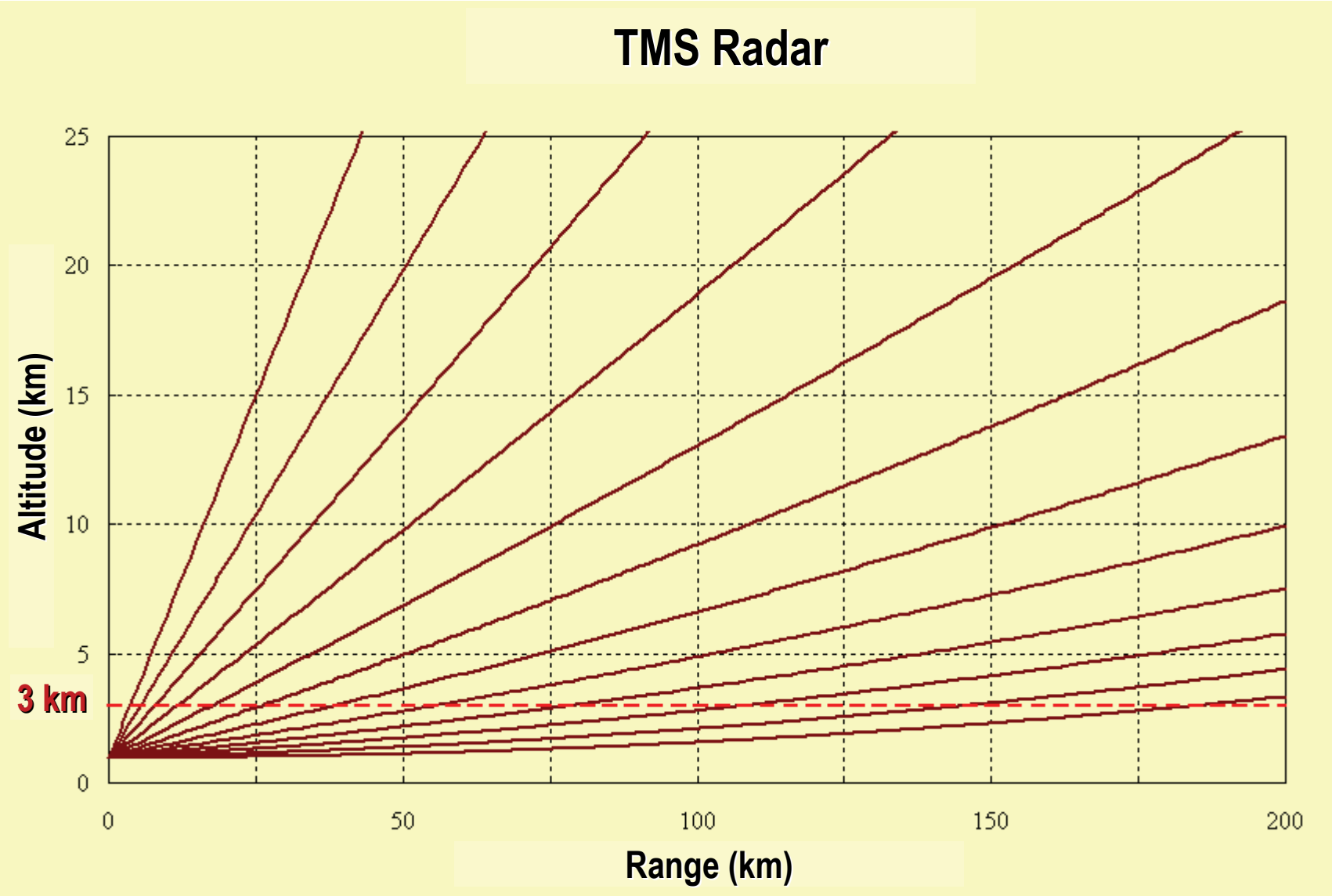




CAPPI from multi PPI

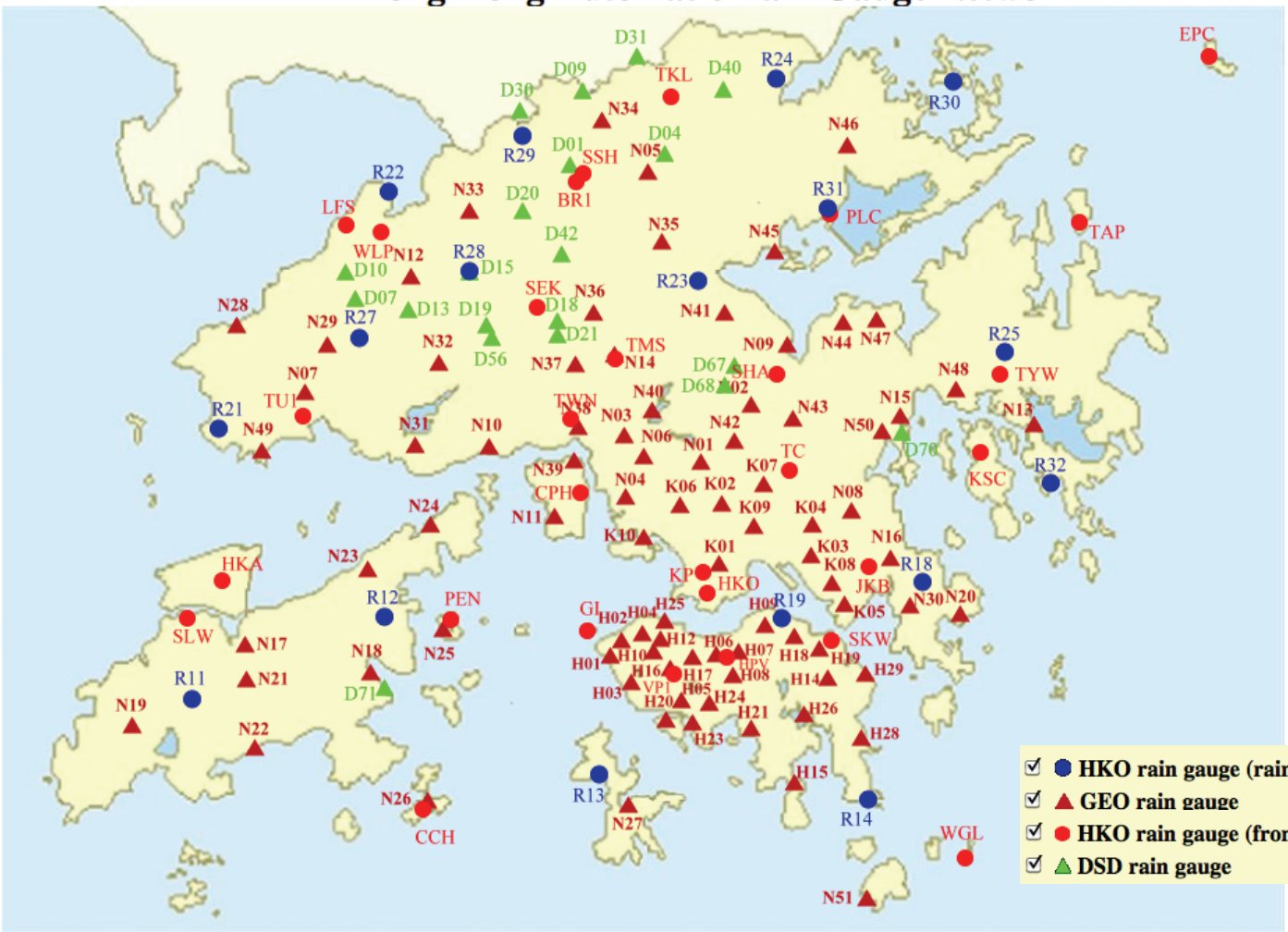
	TMS	TCR	TDWR
Radar level (m)	950	550	59
Antenna diameter (m)	8.5	4.2	7.6
Beam width (deg)	0.8	1.9	0.55
Wavelength (cm)	10.6	10.6	5.3
Transmitter	Klystron	Magnetron	Klystron
Power (kW)	650	500	250
Sidelobe (dB)	-31	-23	-27.7
Gain (dB)	44.2	39	50.1
Scanning strategy	0 - 34° in 12 scans	0 - 34.7° in 12 scans	0.6 - 6° volume/ sector scans
Volume scan (min)	6	6	1

Vertical Coverage Pattern



Raingauge Networks

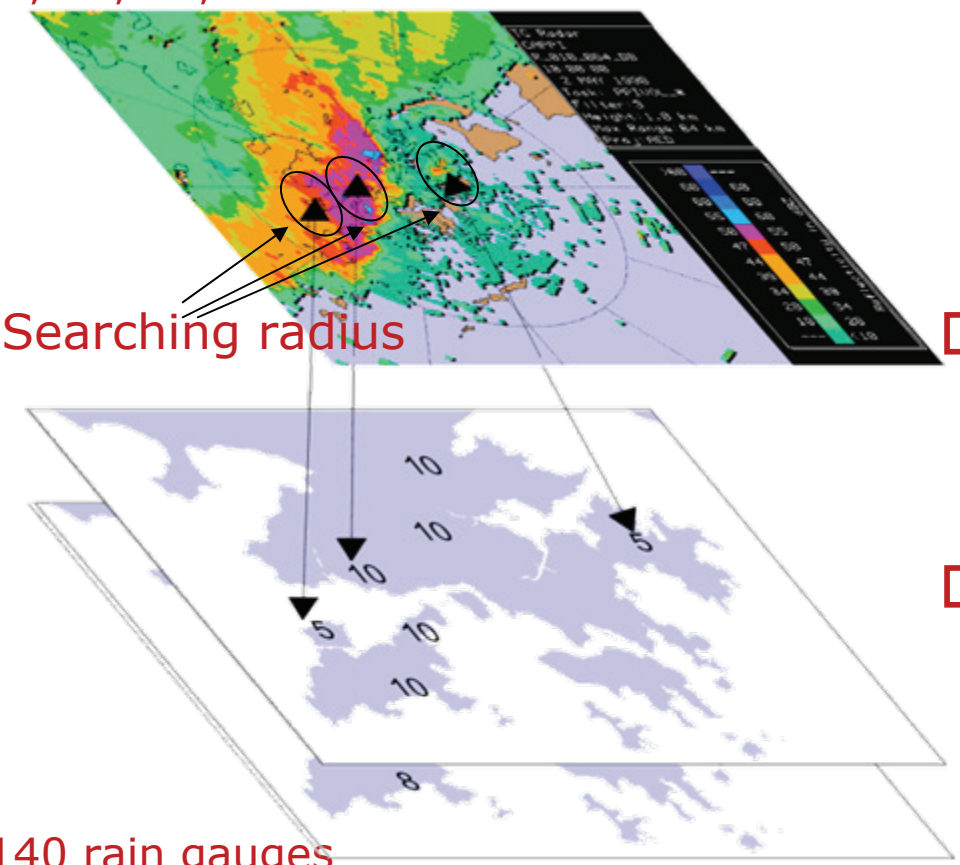
Hong Kong Automatic Rain Gauge Network



Total no. > 150, updated every 1 or 5 min, mean separation ~ 2.6 km

Radar QPE - Reflectivity to Rainfall Rate

1km radar reflectivity
Z: 00, 06, 12, … min



140 rain gauges
R: 05, 10, 15, … min

- Marshall-Palmar relation for converting reflectivity to rainfall rate

$$Z = aR^{b}$$

- seek (a, b) to minimize:

$$\sum_{i=1}^{140} (dBG_i - dBZ_i)^2$$

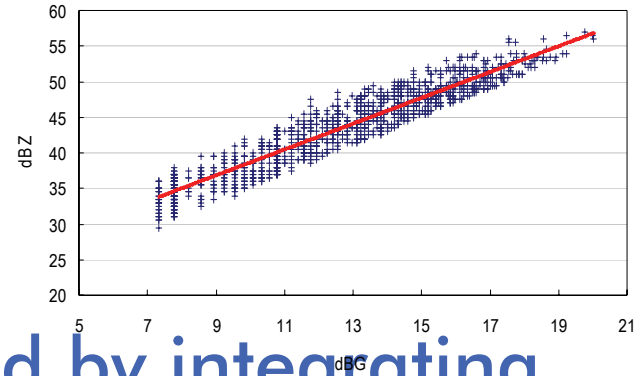
- where

$$dBG_i = 10 \log R_i$$

Dynamic Z-R Calibration

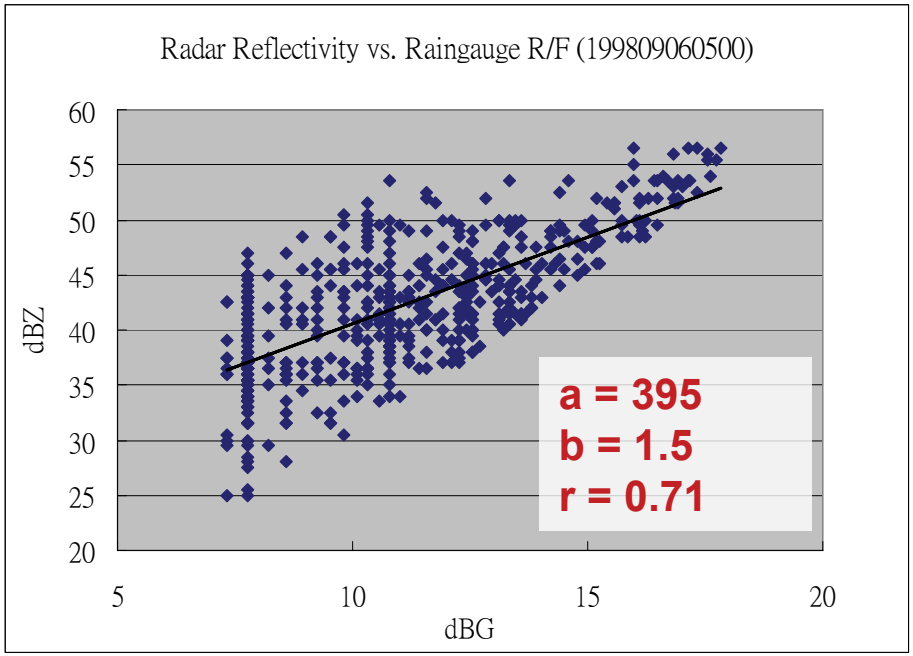
- least square matching (Zawadzki 1987)
- based on latest radar reflectivity and raingauge data
- linear regression to find a & b:

$$\underbrace{dBZ_i}_{y} = \underbrace{b}_{m}\,\underbrace{10\log R_i}_{x} + \underbrace{10\log a}_{c}$$

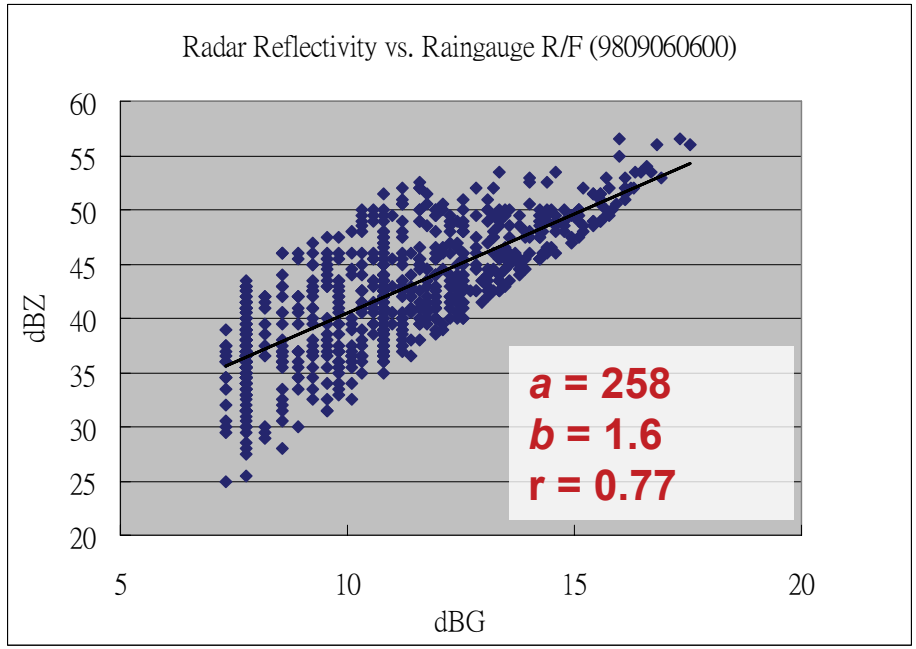


- updated every 5 min
- rainfall accumulations estimated by integrating the rainfall rates at different times
- tends to underestimate

Z-R Calibration Examples



05:00 HKT



06:00 HKT

TC	TC ID	a	b
Kammuri	0212	210	1.4
Hagupit	0218	208	1.3
Imbudo	0307	210	1.4
Krovanh	0312	224	1.3
Dujuan	0313	238	1.3

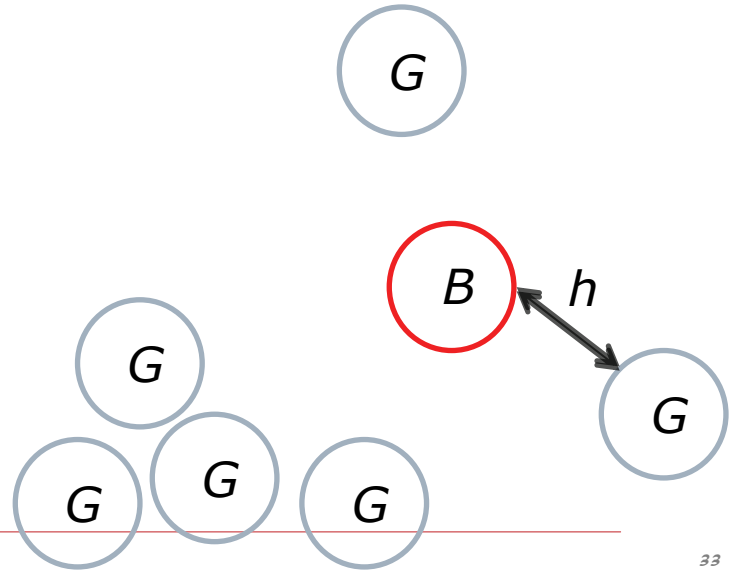
Raingauge-based QPE

- **grid-point analysis by Barnes method**
  - *interpolation with Gaussian weighting according to distance between data & estimation point:*

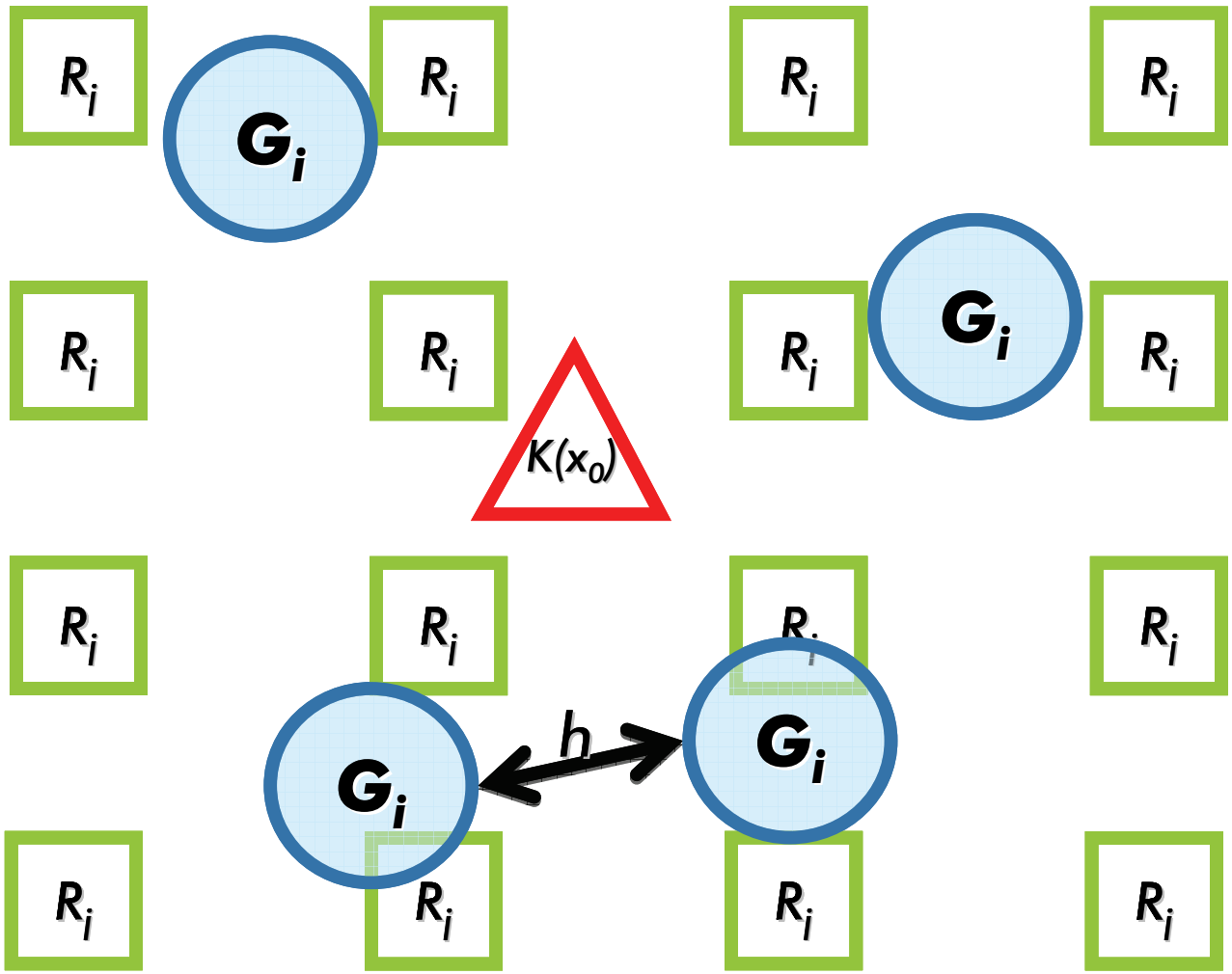
$$B(x_0) = \frac{\sum_{i=1}^{N_0} w_i G_i}{\sum_{i=1}^{N_0} w_i} \qquad w_i = \exp\left(\frac{-h_i^2}{L^2}\right)$$

  - *plus correction using residuals*
- ***L* is arbitrary**
- **problems:**
  - *boundary*
  - *over/undershoot*
    - eased by post-processing

B : barnes estimation (mm)
L : radius of influence
N_0 : number of gauge report
G_i : i-th gauge report (mm)
w_i : weight of i-th gauge
h_i : distance between gauge and estimation point



Radar-Raingauge Blending



Optimal Analysis by co-Kriging

co-Kriging estimate: $K(x_0) = \sum_{i=1}^{N_0} \lambda_i(x_0) G_i + \sum_{j=1}^{M_0} \lambda_j(x_0) R_j$

seek to minimize: $\sigma^2 = E\left\{\left[K(x_0) - G(x_0)\right]^2\right\}$

subject to constraints: $\sum_{i=1}^{N_0} \lambda_i(x_0) = 1$ & $\sum_{j=1}^{M_0} \lambda_j(x_0) = 0$

Solution:

$$\sum_{i=1}^{N_0} \lambda_i(x_0)\gamma_{GG}(x_n, x_i) + \sum_{j=1}^{M_0} \lambda_j(x_0)\gamma_{GR}(x_n, x_j) + \mu_G(x_0) = \gamma_{GG}(x_n, x_0), \quad \text{for } n = 1, \cdots, N_0$$

$$\sum_{i=1}^{N_0} \lambda_i(x_0)\gamma_{RG}(x_m, x_i) + \sum_{j=1}^{M_0} \lambda_j(x_0)\gamma_{RR}(x_m, x_j) + \mu_R(x_0) = \gamma_{RG}(x_m, x_0), \quad \text{for } m = 1, \cdots, M_0$$

Solutions

Empirical Variograms & Cross-variogram:

$$\gamma_{GG}(h) = \frac{1}{2P_1(h)} \sum_{k=1}^{P_1(h)} \left[G(x_k + h) - G(x_k) \right]^2$$

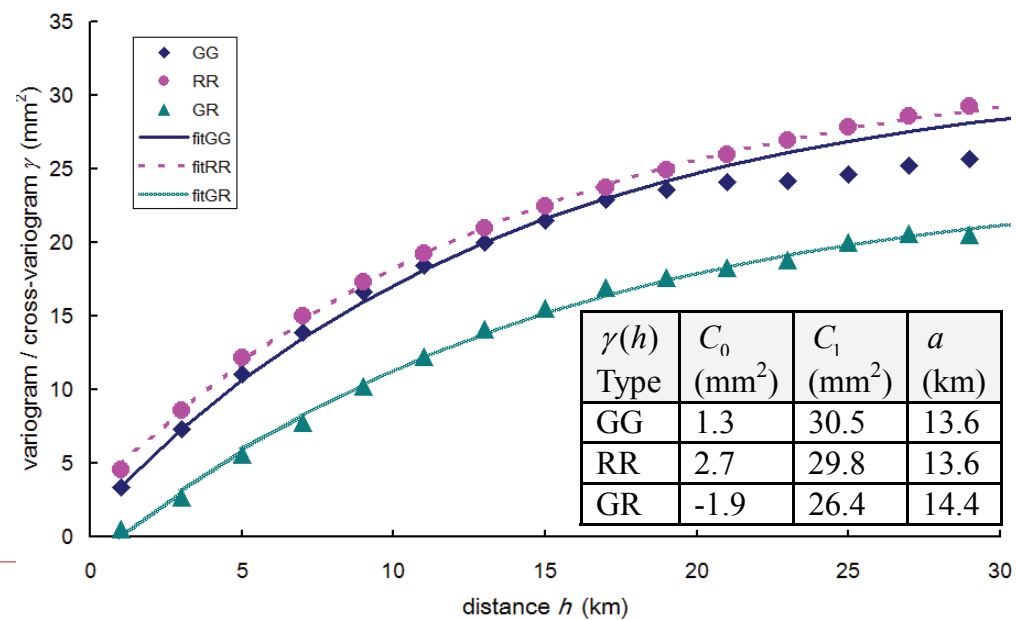
$$\gamma_{RR}(h) = \frac{1}{2P_2(h)} \sum_{k=1}^{P_2(h)} \left[R(x_k + h) - R(x_k) \right]^2$$

$$\gamma_{GR}(h) = \frac{1}{2P_3(h)} \sum_{k=1}^{P_3(h)} \left[G(x_k + h) - G(x_k) \right] \left[R(x_k + h) - R(x_k) \right]$$

Modeling Variogram:

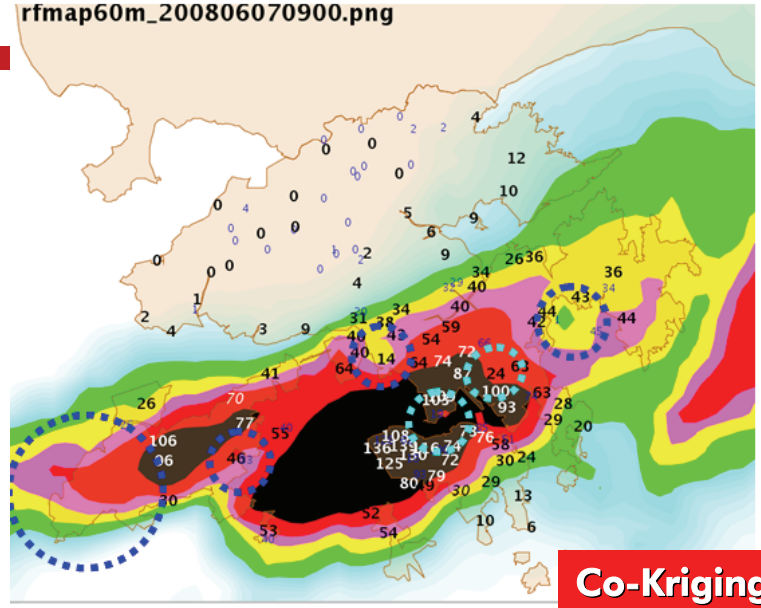
$$\gamma(h) = \begin{cases} 0 & \text{if} \quad h = 0 \\ C_0 + C_1 \left(1 - e^{-h/a} \right) & \text{if} \quad h > 0 \end{cases}$$

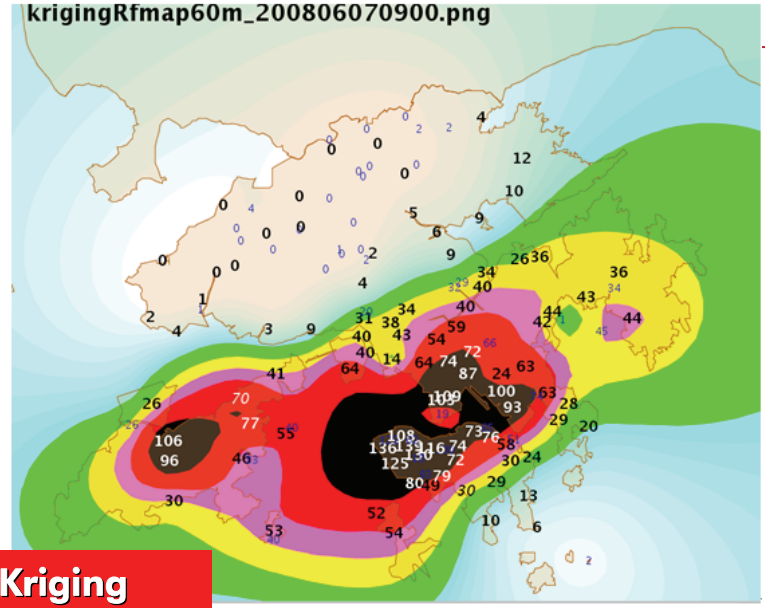
where $C_0 = \text{nugget}$, $C_1 = \text{sill}$, $a = \text{range}$



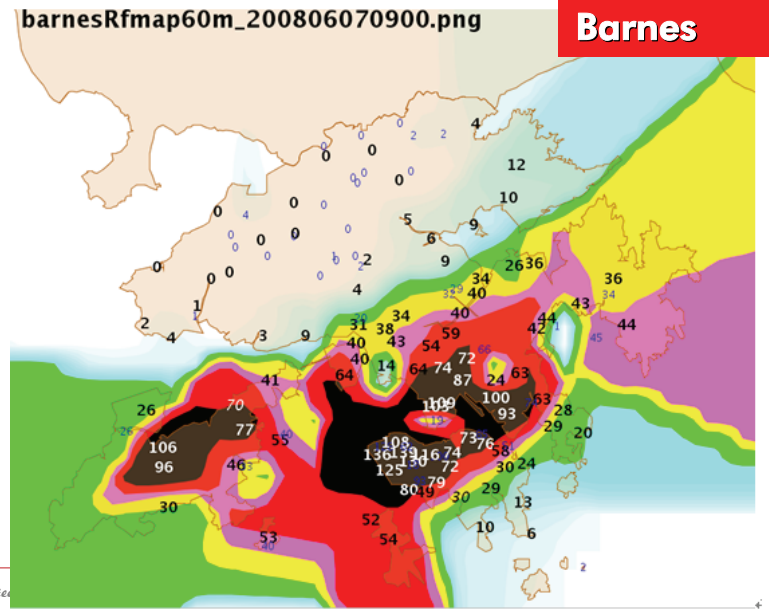
$\gamma(h)$ Type	C_0 (mm^2)	C_1 (mm^2)	a (km)
GG	1.3	30.5	13.6
RR	2.7	29.8	13.6
GR	-1.9	26.4	14.4

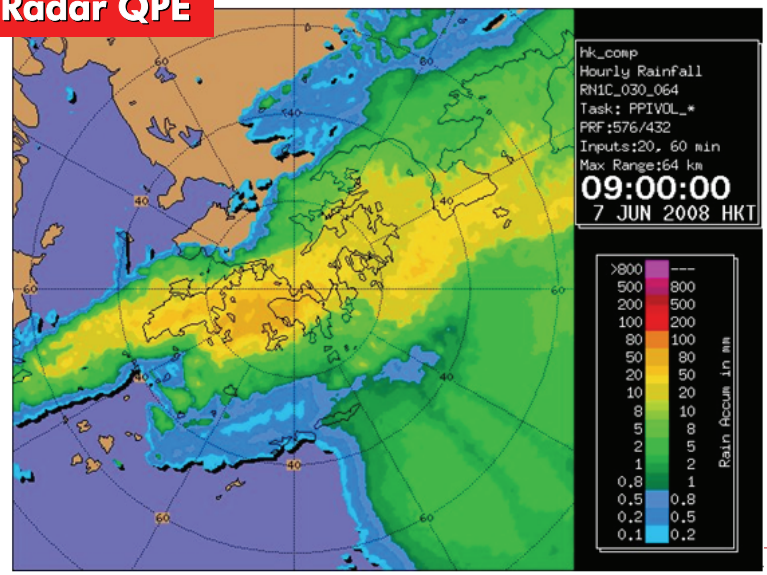
Application to Grid Analysis





Co-Kriging	Kriging
Barnes	Radar QPE



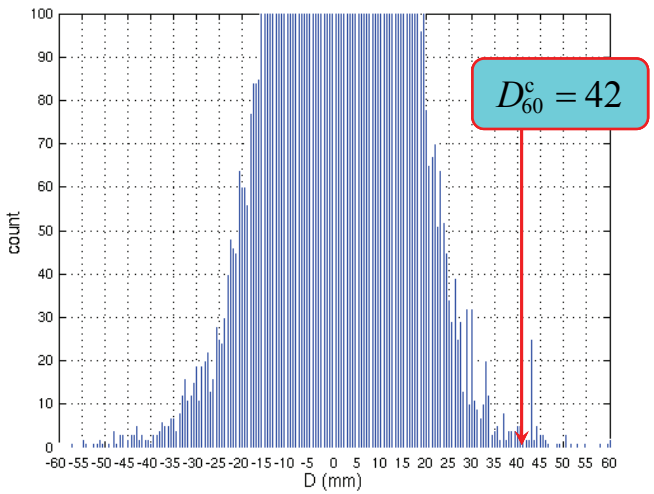


How Good is Co-Kriging QPE?

Gridded QPE errors (in mm) in gauge sparse situations during five rainstorm cases in 2010

Date (2010)	Mean error			RMS error		
	Barnes	*Kriging*	*co-Kriging*	*Barnes*	*Kriging*	*co-Kriging*
22 Jul	-1.02	-1.43	-0.95	9.54	9.06	8.86
28 Jul	-1.37	-1.89	-1.90	10.30	9.55	7.29
5 Aug	-0.94	-1.08	-1.01	6.55	6.06	6.43
10 Sep	-1.08	-1.35	-0.31	10.77	9.75	7.57
21 Sep	-0.51	-0.90	-1.45	6.22	5.86	6.70
Mean	*-0.99*	*-1.34*	*-1.13*	*8.90*	*8.25*	*7.42*

Application to Raingauge Locations



RG-QPE Residuals

- **linear residual (departure):**

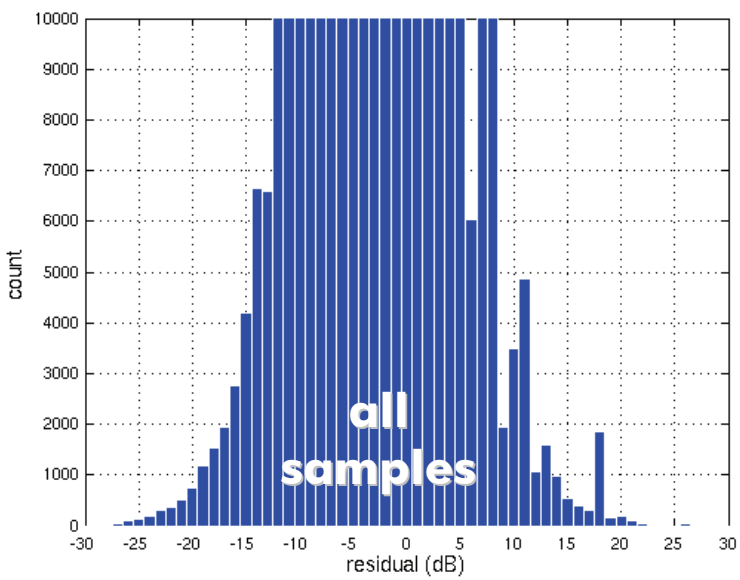
$$D = G - K$$

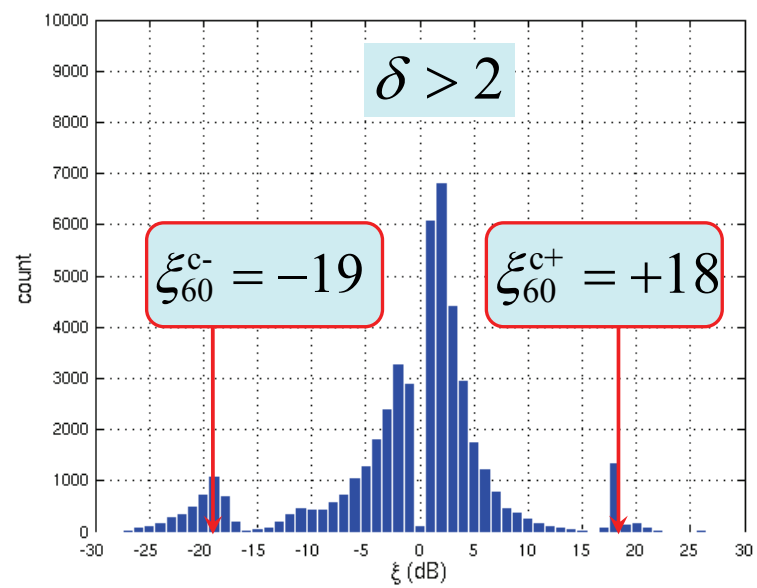
- **log residual:**

$$\xi \equiv 10\log(G/K) = 10\log G - 10\log K$$

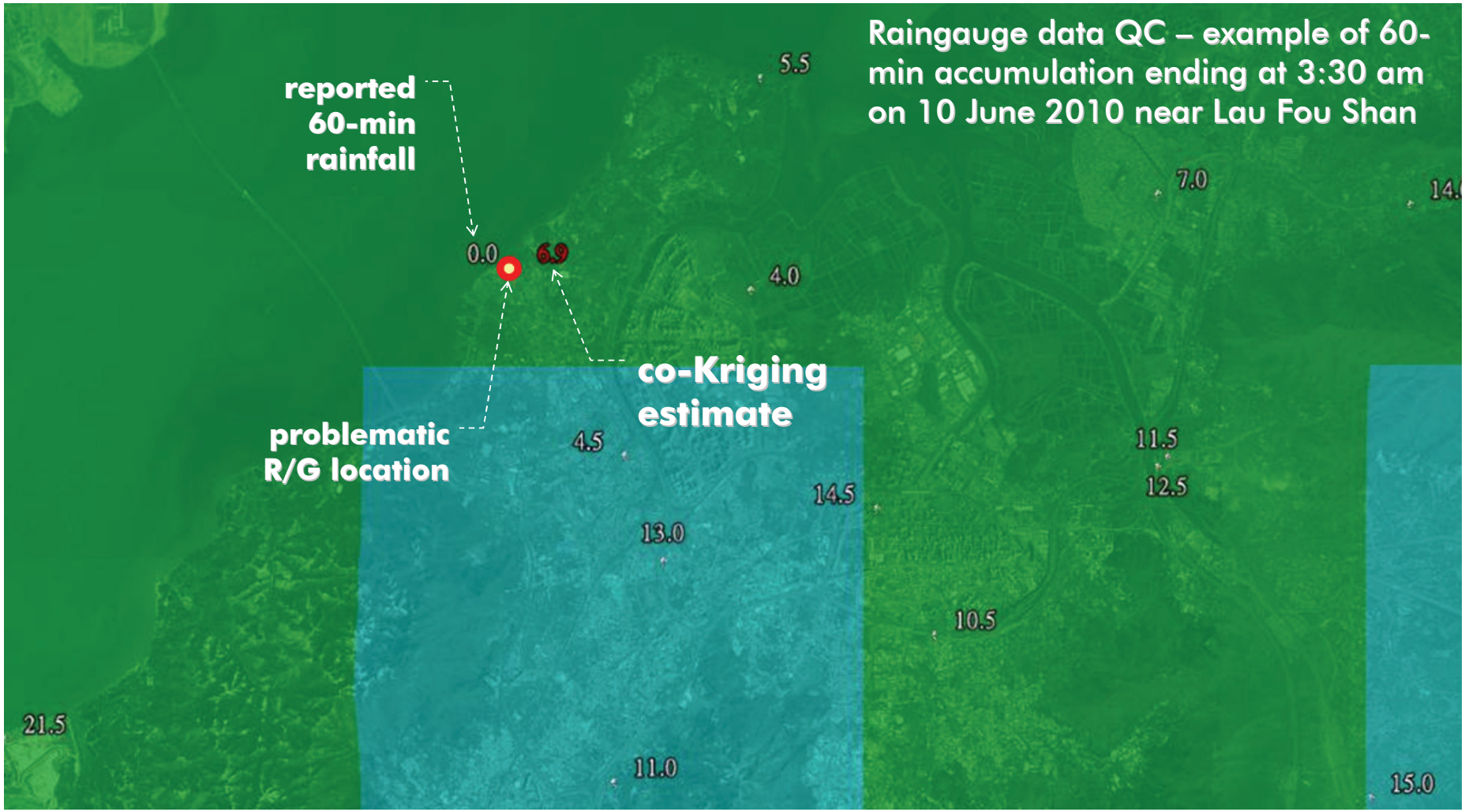
- **standardized residual:**

$$\delta \equiv |G - K|/\sigma = |D|/\sigma$$





R/G Data QC Example



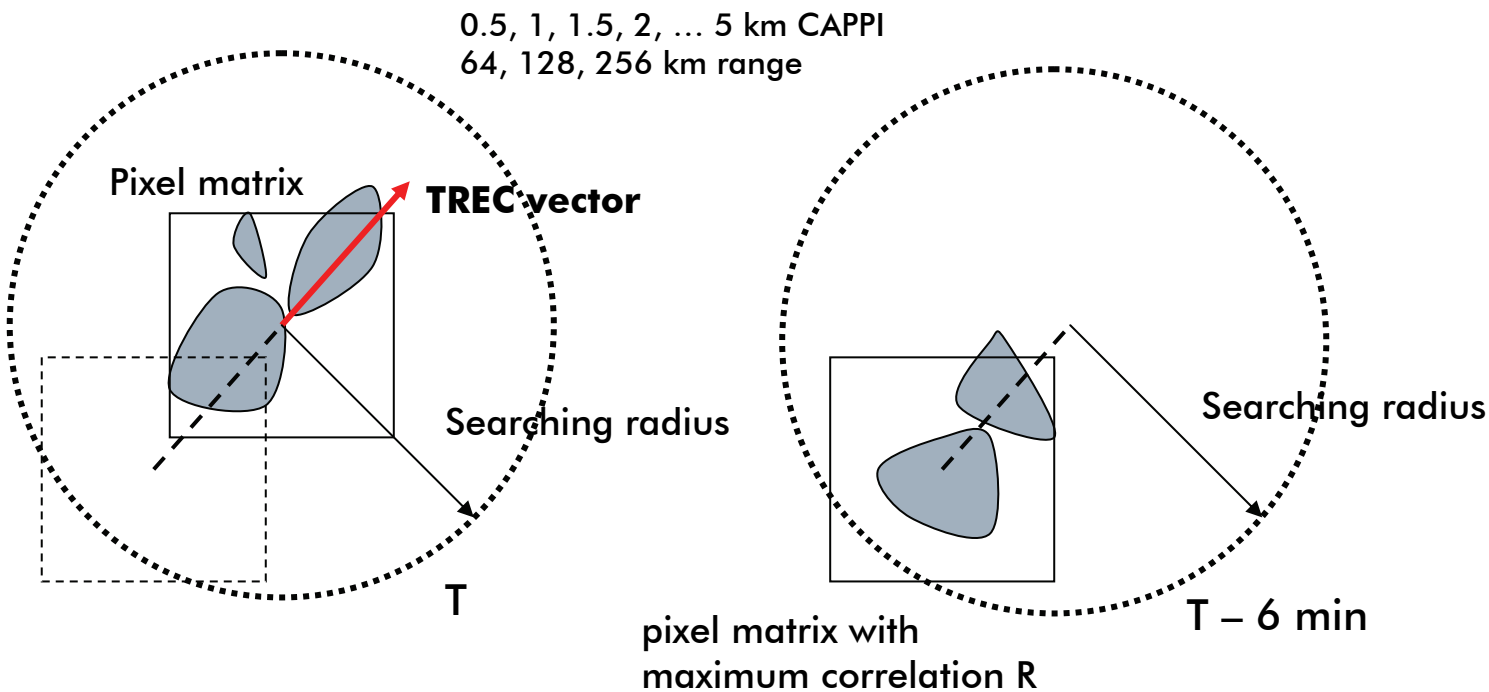
UNESCAP/WMO
Typhoon Committee

United Nations
ESCAP

WMO OMM

Radar-Echo Motion Tracking

TREC (Tracking of Radar Echo by Correlation)

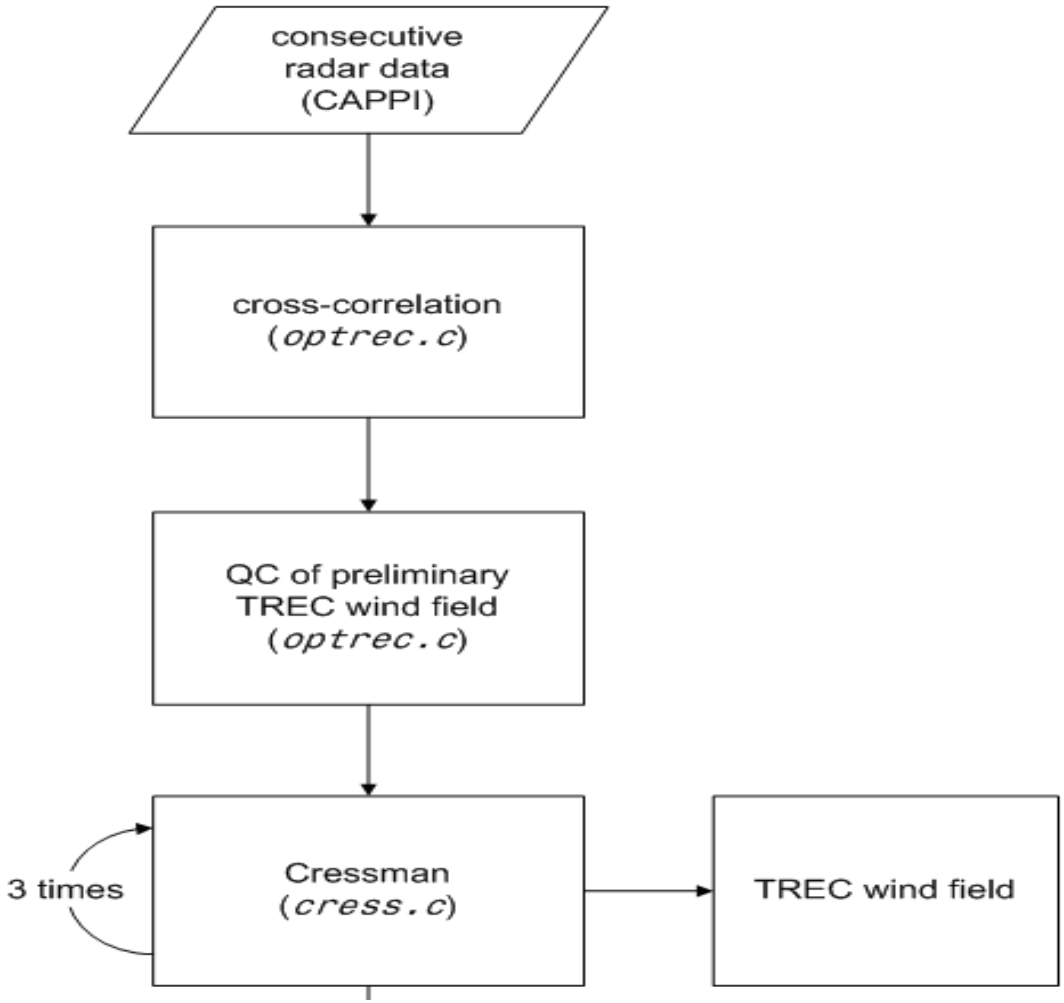


where Z_1 and Z_2 are the reflectivity at T+0 and T+6min respectively

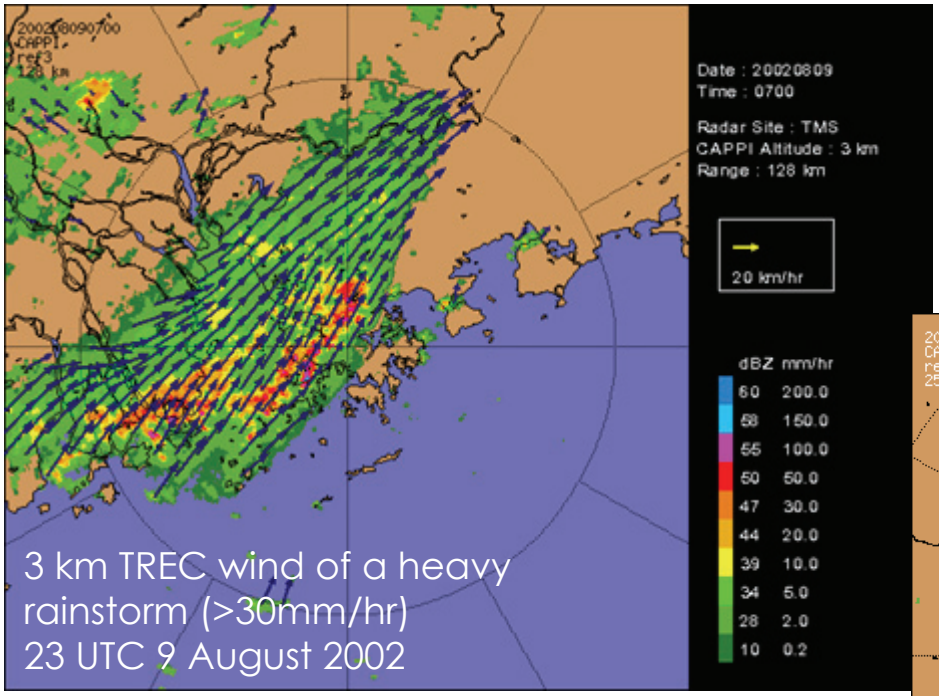
$$R = \frac{\sum_k Z_1(k) \times Z_2(k) - \frac{1}{N}\sum_k Z_1(k)\sum_k Z_2(k)}{\left[\left(\sum_k Z_1^2(k) - N\overline{Z_1}^2\right)\times\left(\sum_k Z_2^2(k) - N\overline{Z_2}^2\right)\right]^{1/2}}$$

Searching radius: 5, 10, 20 km (64, 128 and 256 km CAPPI)
Pixel matrix size: 5, 10, 20 km (64, 128 and 256 km CAPPI)
Max resolvable: 50, 100, 200 km/h (64, 128 and 256 km CAPPI)
Resolution: 1.3, 2.6, 5.2 km/h (64, 128 and 256 km CAPPI)

Basic Program Flow of TREC



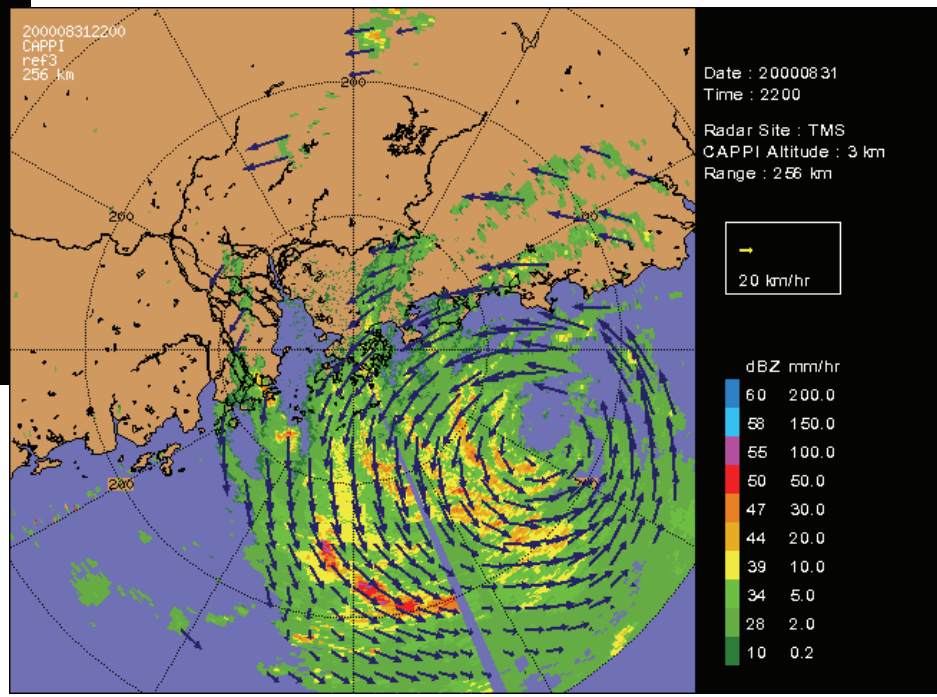
TREC Examples



3 km TREC wind of a heavy rainstorm (>30mm/hr)
23 UTC 9 August 2002

SW'lies with embedded waves

Asymmetric wind distribution
(Stronger to the right, weaker to the left)



3 km TREC wind of Typhoon Maria
31 August 2000

Optical Flow

- [HS80] Horn, B.K.P. and B.G. Schunck (1980): Determining optical flow. AI Memo 572, MIT
  - *"Optical flow is the distribution of apparent velocities of movement of brightness patterns in an image …"*

- Given I(x,y,t) the image brightness at point (x,y) at time t, and the brightness is constant when pattern moves:

$$\frac{dI(x,y,t)}{dt} = 0$$

Optical Flow (2)

- Using chain rule for differentiation, then

$$\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y} = 0$$

where

$$u = \frac{dx}{dt} \quad \text{and} \quad v = \frac{dy}{dt}$$

- N.B. u and v are retrieved assuming uniform flow over a particular block of pixels in imagery

Optical Flow (3)

- OF can be formulated as minimization of the following cost function to retrieve u(x,y) and v(x,y):

$$J = \iint \left[\frac{\partial I}{\partial t} + u \frac{\partial I}{\partial x} + v \frac{\partial I}{\partial y} \right]^2 dxdy$$

- In Lagrangian frame of reference, the minimization can also be written as:

$$J = \iint \left[\frac{dI}{dt} \right]^2 dxdy = \iint \left[I(\vec{r}) - I(\vec{r} - \vec{v}\Delta t) \right]^2 dxdy$$

Laroche and Zawadzki (1995)

Smoothness constraint

- **HS80:**
  - *Minimize gradient of optical flow velocities:*

$$\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 \quad \text{and} \quad \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2$$

- **Thacker (1988):**
  - *Laplacian of flow velocities:*

$$\nabla^2 u = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \quad \text{and} \quad \nabla^2 v = \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}$$

Smoothness constraint

- Wahba and Wendelberger (1980)

$$\left(\frac{\partial^2 u}{\partial x^2}\right)^2 + \left(\frac{\partial^2 u}{\partial y^2}\right)^2 + 2\left(\frac{\partial^2 u}{\partial x \partial y}\right) \quad \text{and} \quad \left(\frac{\partial^2 v}{\partial x^2}\right)^2 + \left(\frac{\partial^2 v}{\partial y^2}\right)^2 + 2\left(\frac{\partial^2 v}{\partial x \partial y}\right)$$

Implementation of Multiscale Optical-flow by Variational Analysis (MOVA) for radar imagery

- Given three radar CAPPI imagery at t_0, t_1 and t_2 (t_{i+1}-t_i = 6 min)
  - *Two time-level scheme:*

$$\min: \quad J = \iint \left[\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y} \right]^2_{t_o \to t_2} dxdy$$

  - *Three time-level scheme:*

$$\min: \quad J = \iint \left(\left[\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y} \right]^2_{t_o \to t_1} + \left[\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y} \right]^2_{t_1 \to t_2} \right) dxdy$$

  - *Both schemes are implemented in MOVA*

Issues on quality of reflectivity

- To account for data quality of reflectivity (range dependent issue, cluttered pixel, partial block rays, etc), a multiplicative factor is considered in cost function:

$$\min: \quad J = \iint \beta(x,y)\left[\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y}\right]^2 dxdy$$

where $\beta(x,y) = [0,1]$

- N.B. $\beta(x,y) = 1.0$ by default in MOVA

Cost function in MOVA:

$$J = J_I + J_S$$

$$J_I = \iint \beta(x,y)\left[\frac{\partial I}{\partial t} + u\frac{\partial I}{\partial x} + v\frac{\partial I}{\partial y}\right]^2 dxdy$$

$$J_S = \gamma \iint \left[\left(\frac{\partial^2 u}{\partial x^2}\right)^2 + \left(\frac{\partial^2 u}{\partial y^2}\right)^2 + 2\left(\frac{\partial^2 u}{\partial x \partial y}\right) + \left(\frac{\partial^2 v}{\partial x^2}\right)^2 + \left(\frac{\partial^2 v}{\partial y^2}\right)^2 + 2\left(\frac{\partial^2 v}{\partial x \partial y}\right)\right] dxdy \quad \text{(WW80)}$$

$$J_S = \gamma \iint \left[\left(\left(\frac{\partial^2 u}{\partial x^2}\right) + \left(\frac{\partial^2 u}{\partial y^2}\right)\right)^2 + \left(\left(\frac{\partial^2 v}{\partial x^2}\right) + \left(\frac{\partial^2 v}{\partial y^2}\right)\right)^2\right] dxdy \quad \text{(Th88)}$$

Computation steps in MOVA:

- **Given radar CAPPI (single CAPPI in IRIS single-byte format or a vertical layer in CAPPI volume) with dimension N on both x and y dir (N=480).**
- **To compute optical flow velocities (OFV) with dimension M (M<N):**
  - *Compute OFV for M=1 (OFV_1) by minimization*
  - *Apply OFV_1 to translate the imagery at t_0 (or t_0 and t_1 in 3-time-level case)*
  - *Repeat OFV for $M=m_1, m_2, \ldots, m_K$ using different weighting factors of smoothness constraint. Scaling guess procedure in Laroche and Zawadzki is considered.*
  - *Final OFV:*

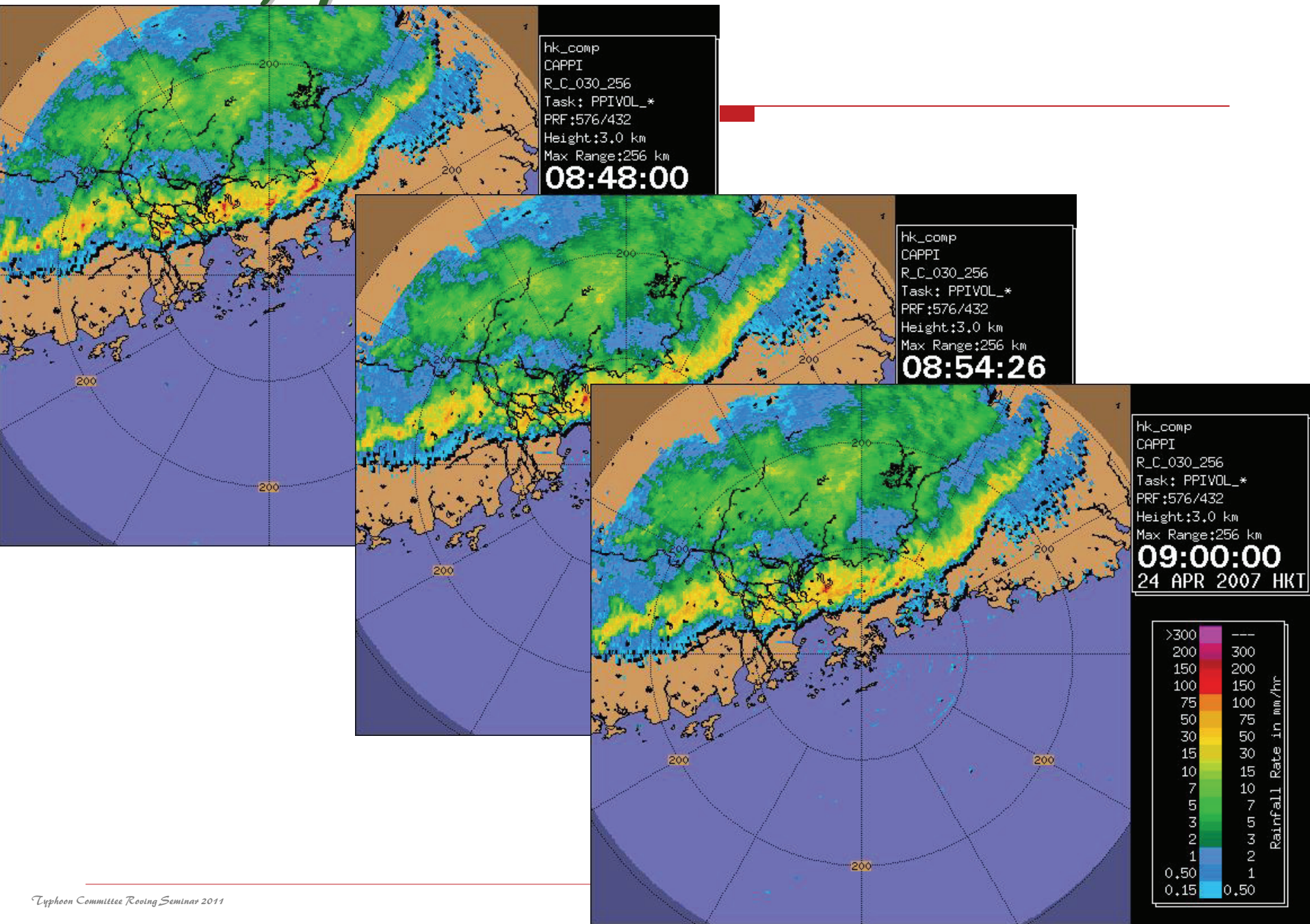
$$OFV = OFV_1 + OFV_{mk}$$

  - *For 128 km range, M=5,10,20,40,80; γ=10,100,100,200,200 ; both can be adjustable in the optional namelist file (fort.1)*

Compare with TREC

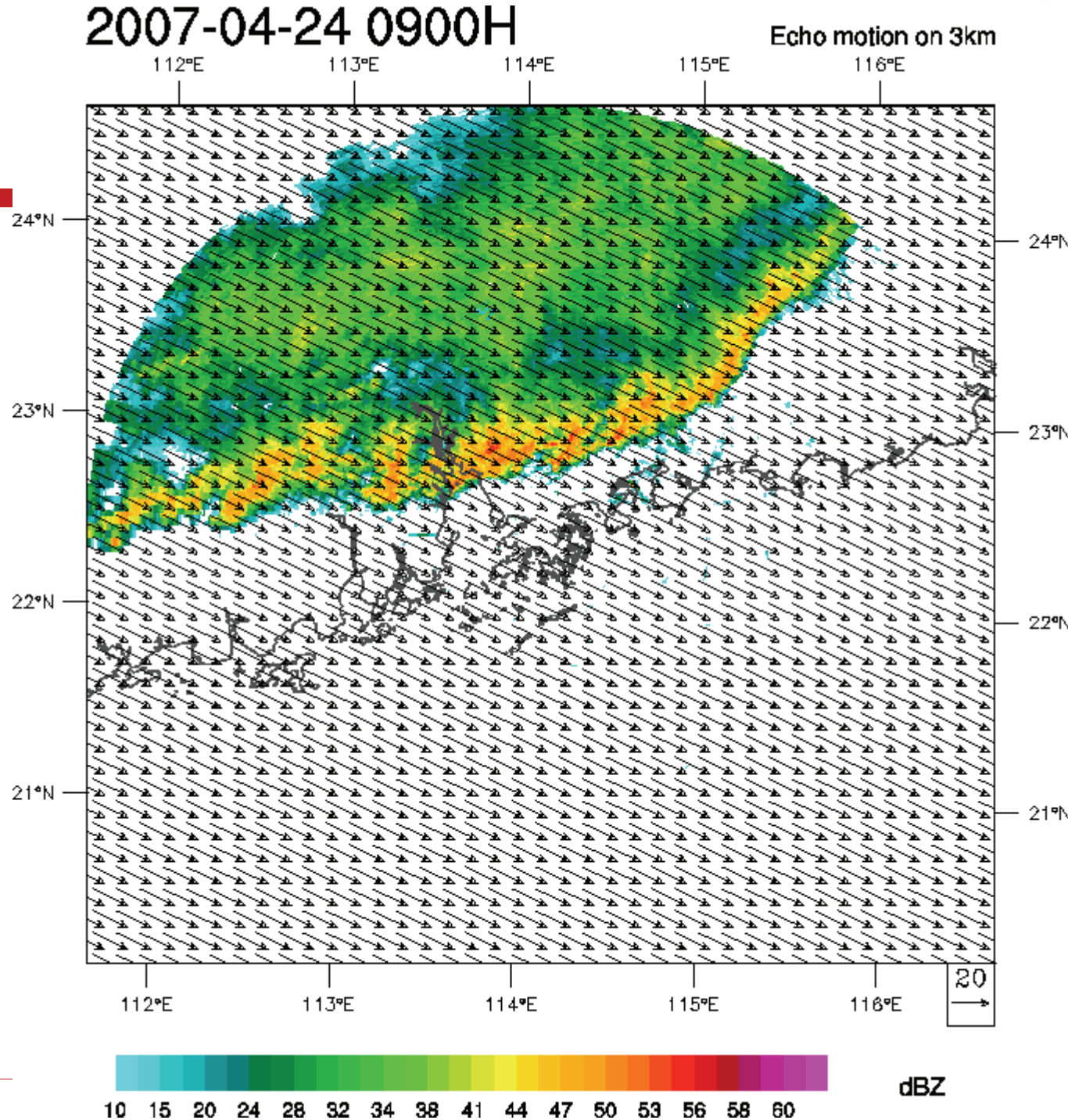
- **Variational analysis:**
  - *Include 'physical' constraints*
  - *Other observation (e.g. Doppler velocity)*
  - *Use previous retrieval or upper level wind forecast from NWP as first guess*
- **Optical flow can also be implemented through many ways**
  - *Fourier transform*
  - *Robust estimators*
  - *Wavelet transform*
  - ….

Case (24 Apr 2007 09:00H)



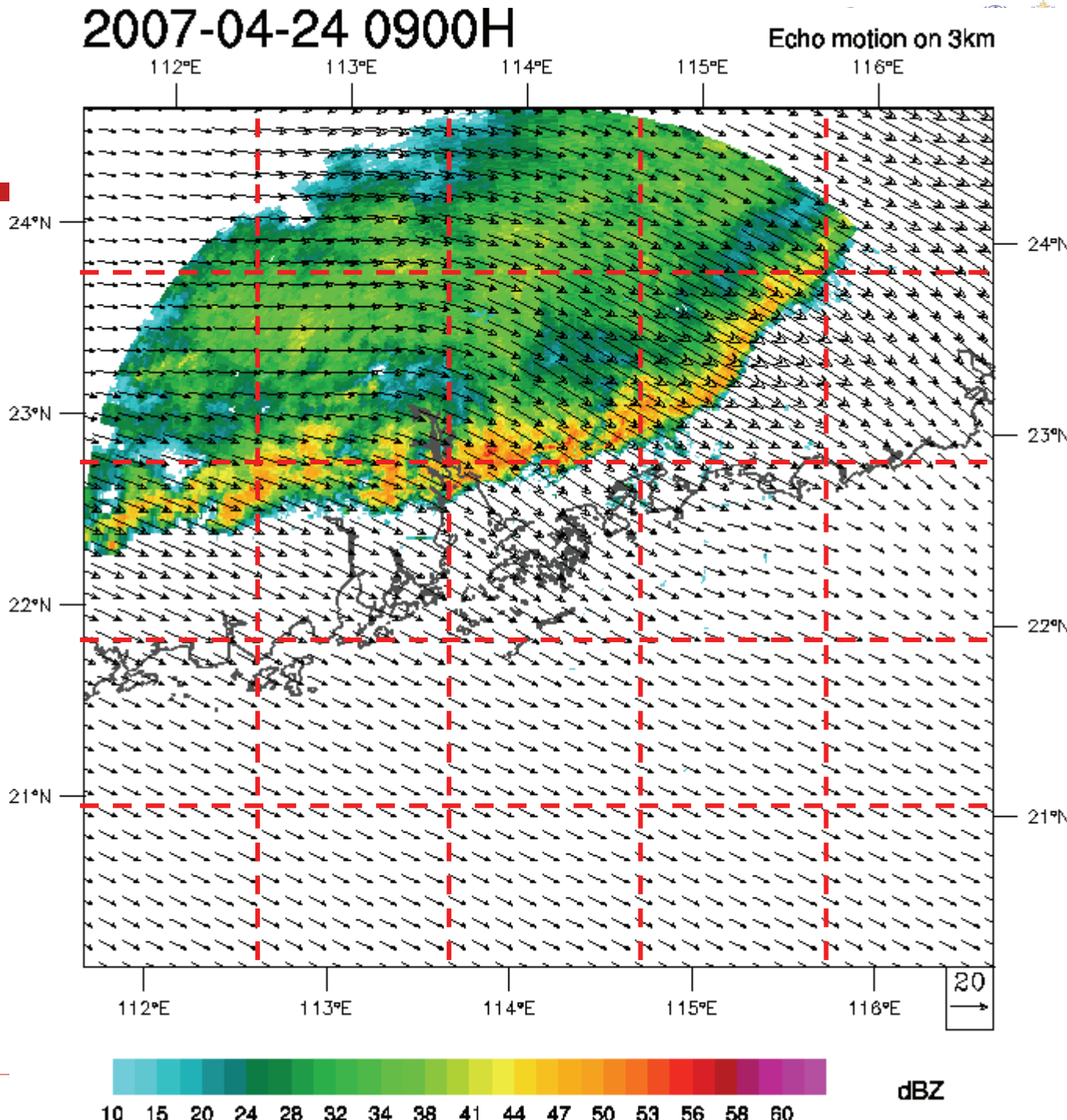
M=1

Single vector over whole domain

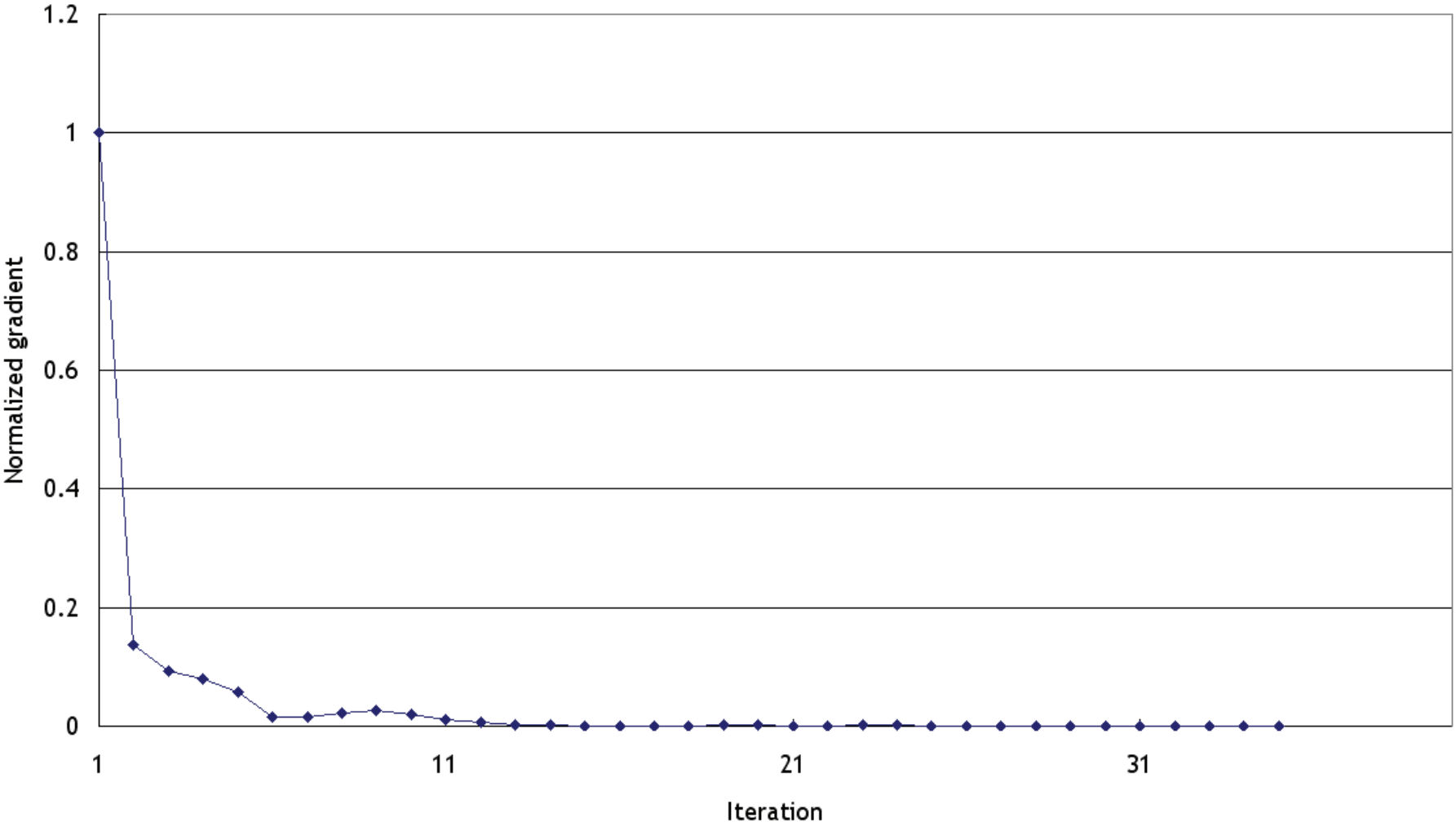


M=5

5x5 vectors



Change in gradient during minimization (M=5)

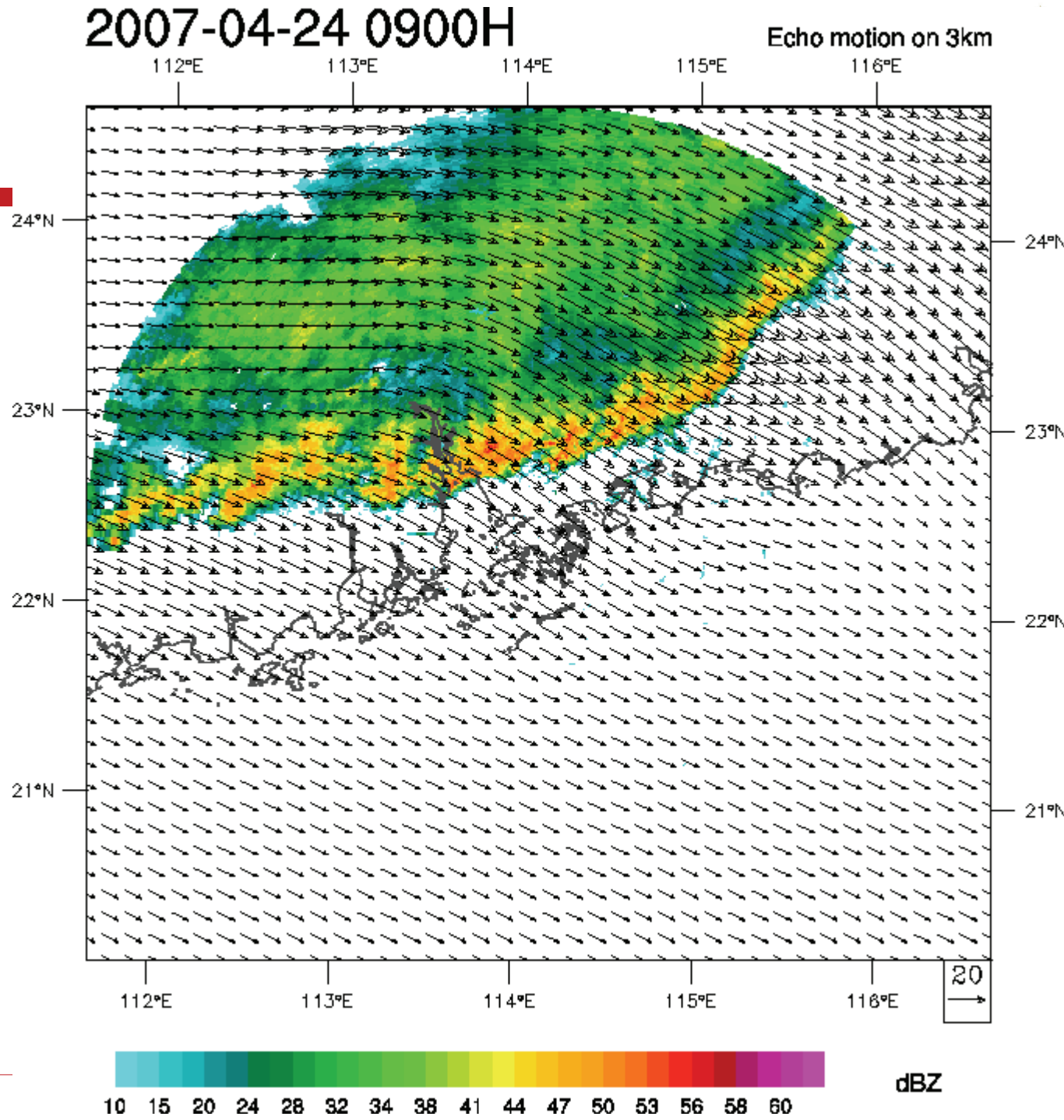


M=10

10x10 vectors

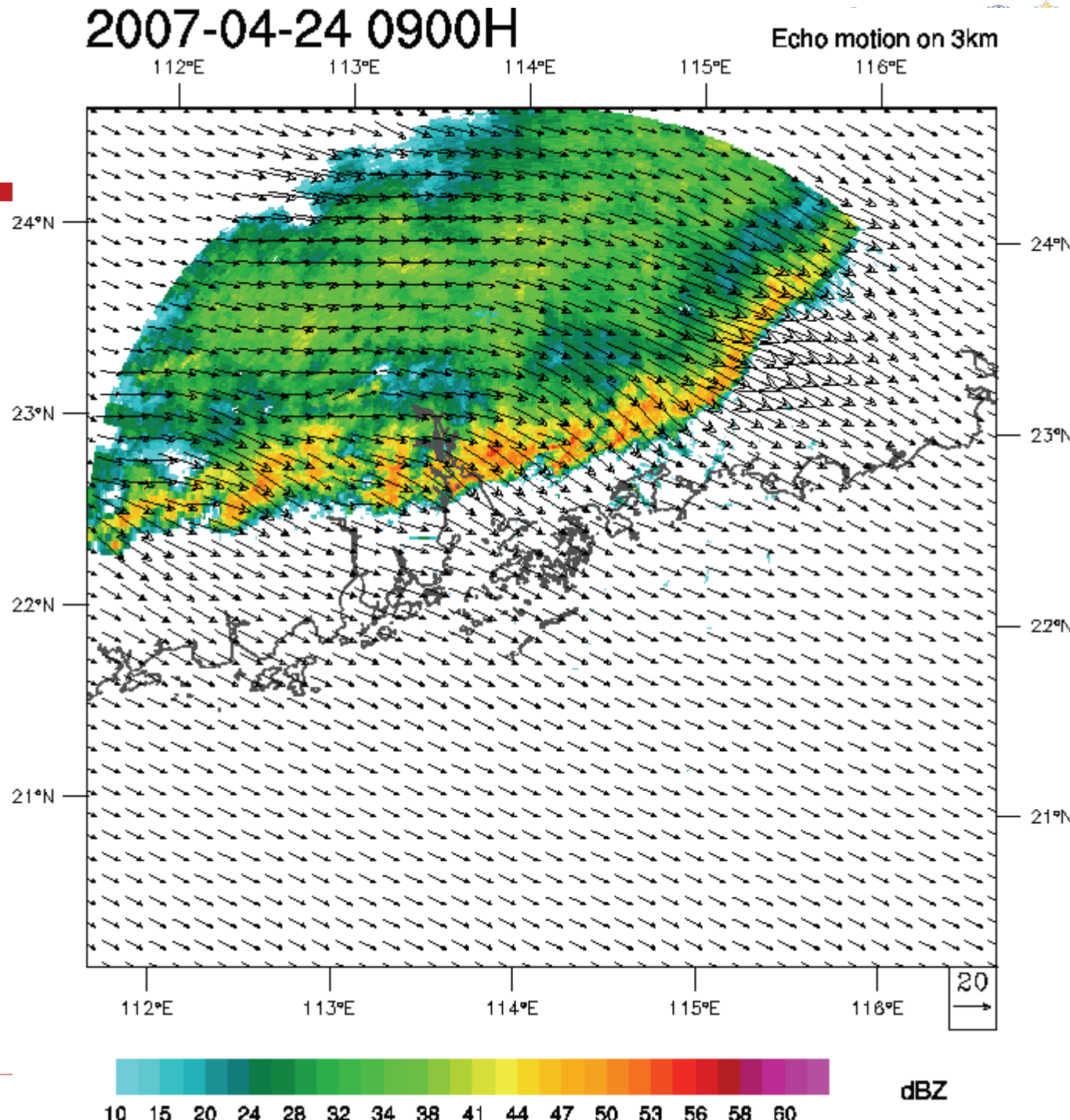
Repeat for

M=20,40 and 80

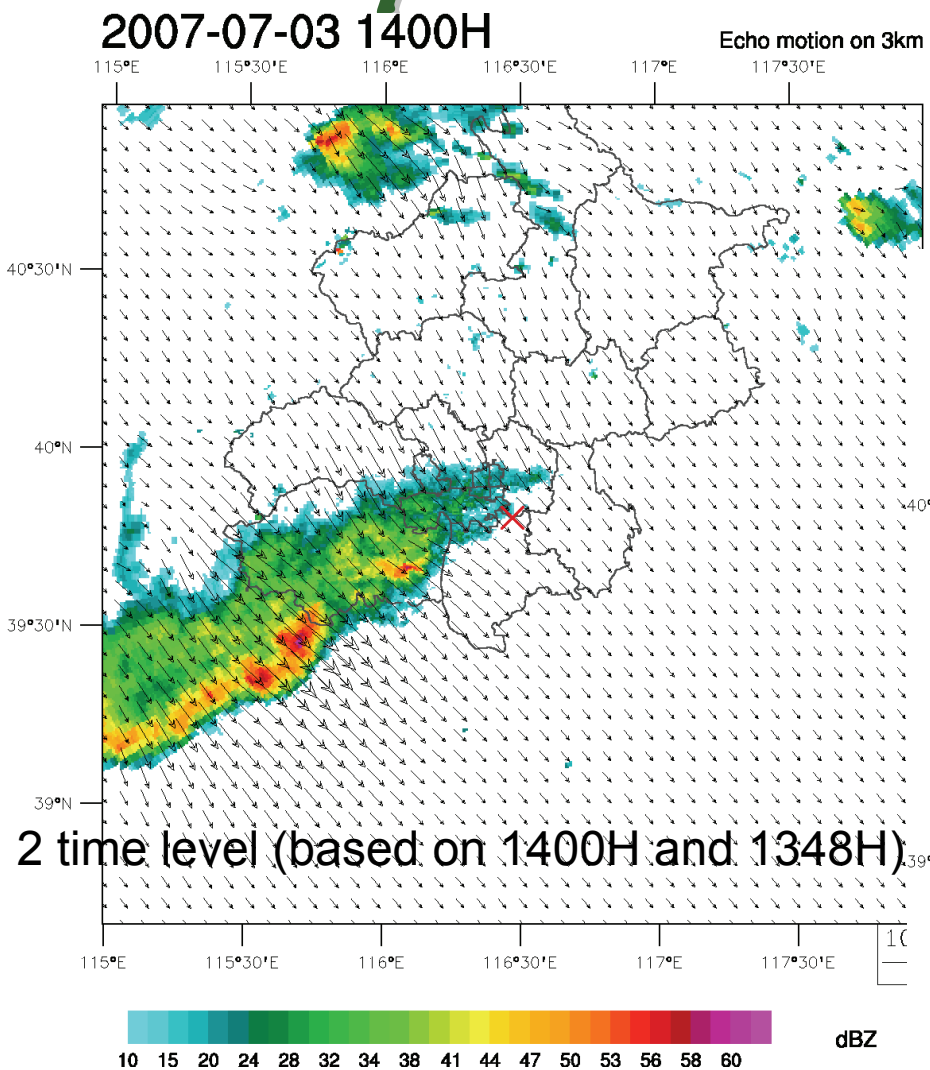


M=80

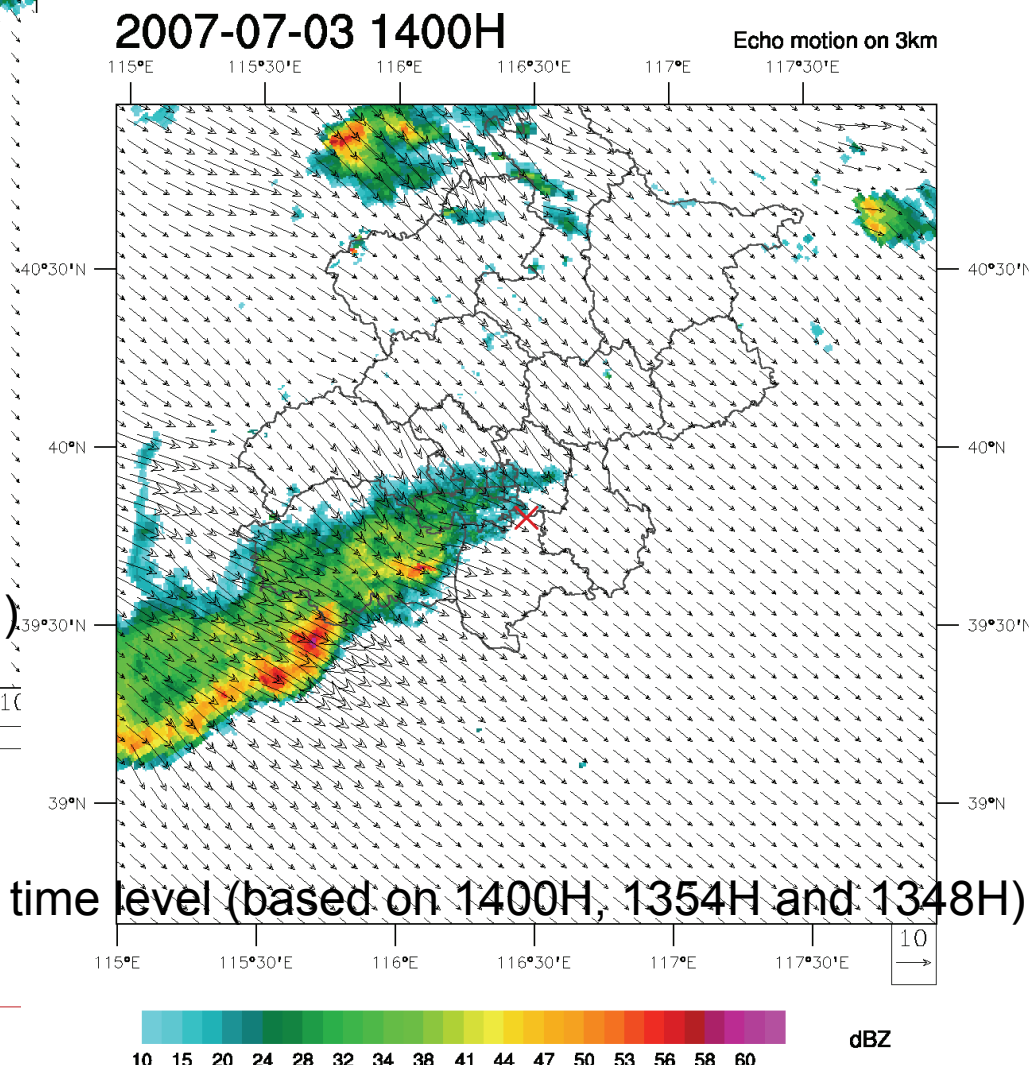
80x80 vectors



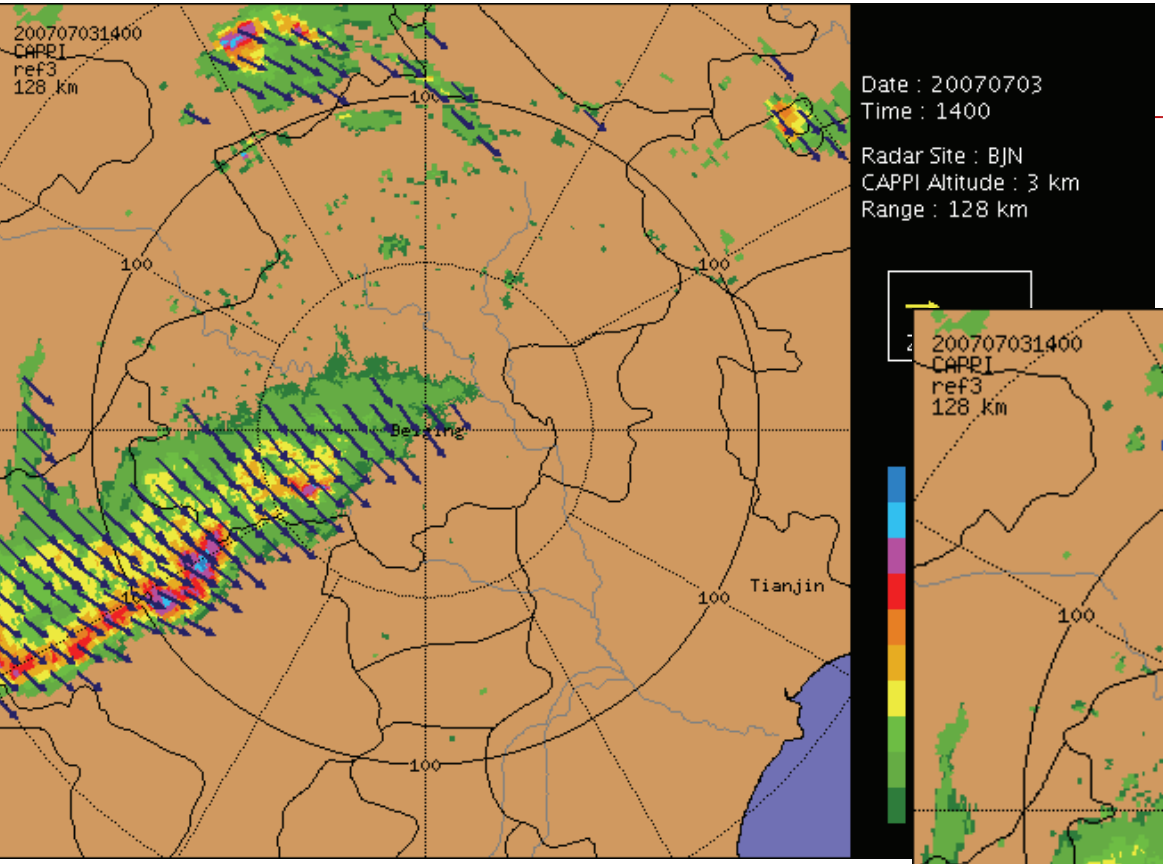
Example

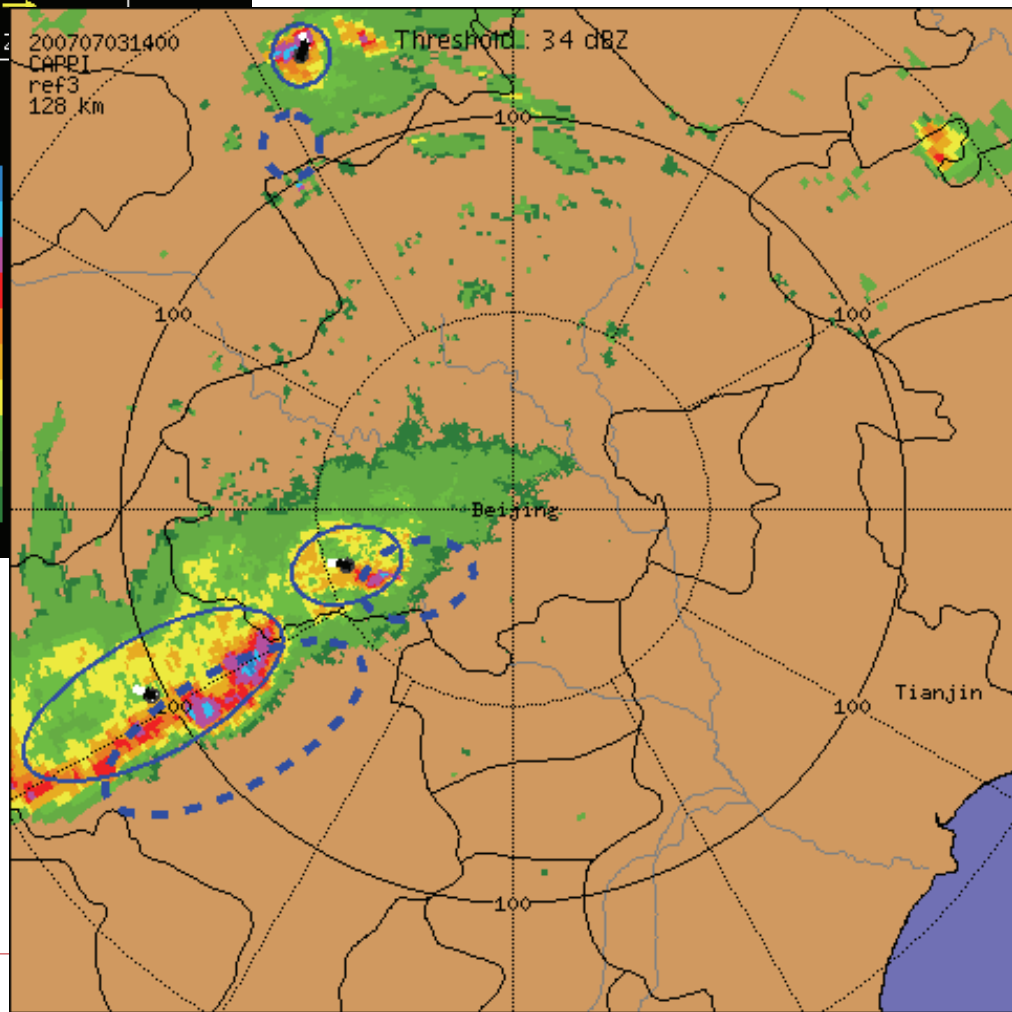


2 time level (based on 1400H and 1348H)



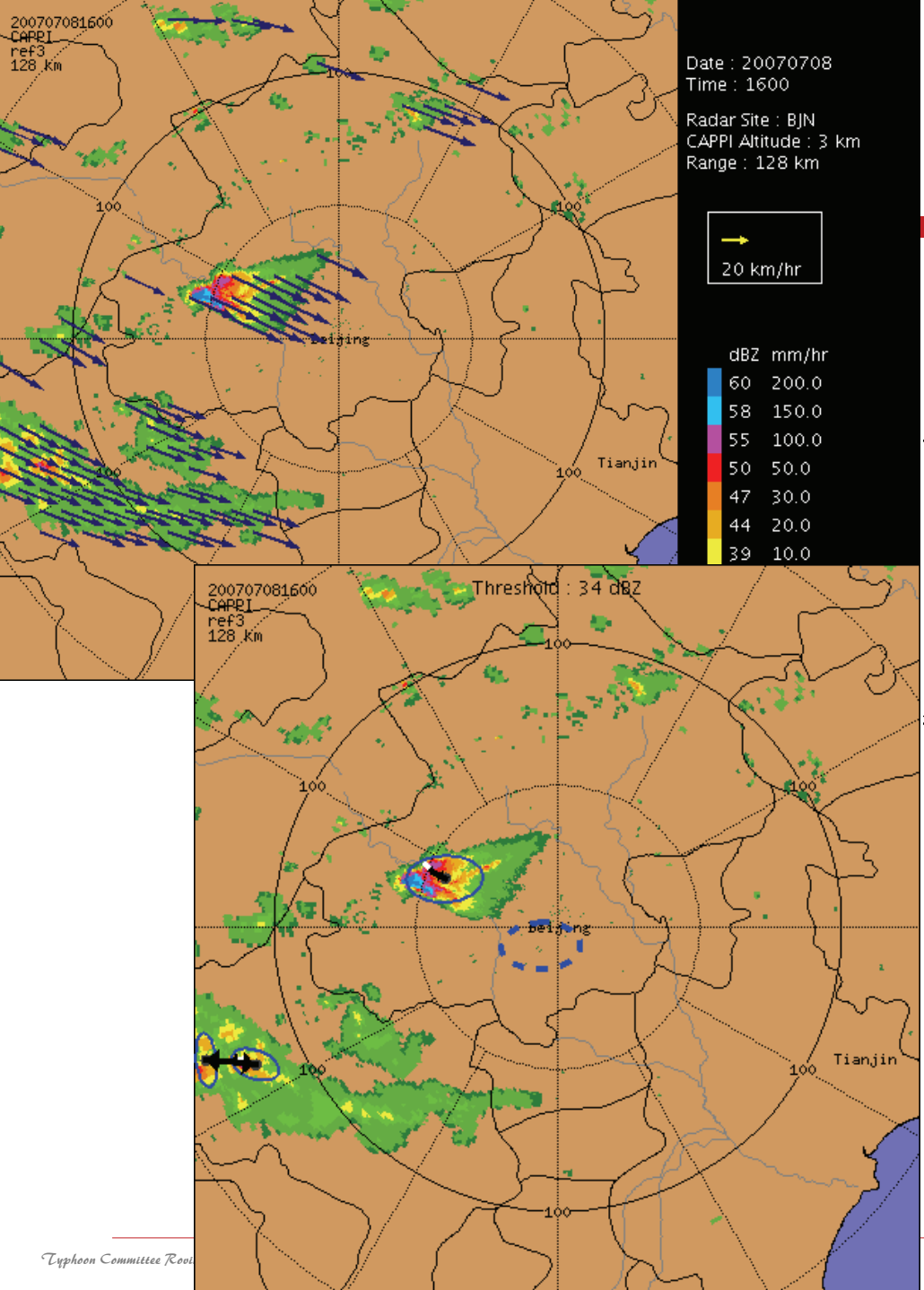
3 time level (based on 1400H, 1354H and 1348H)

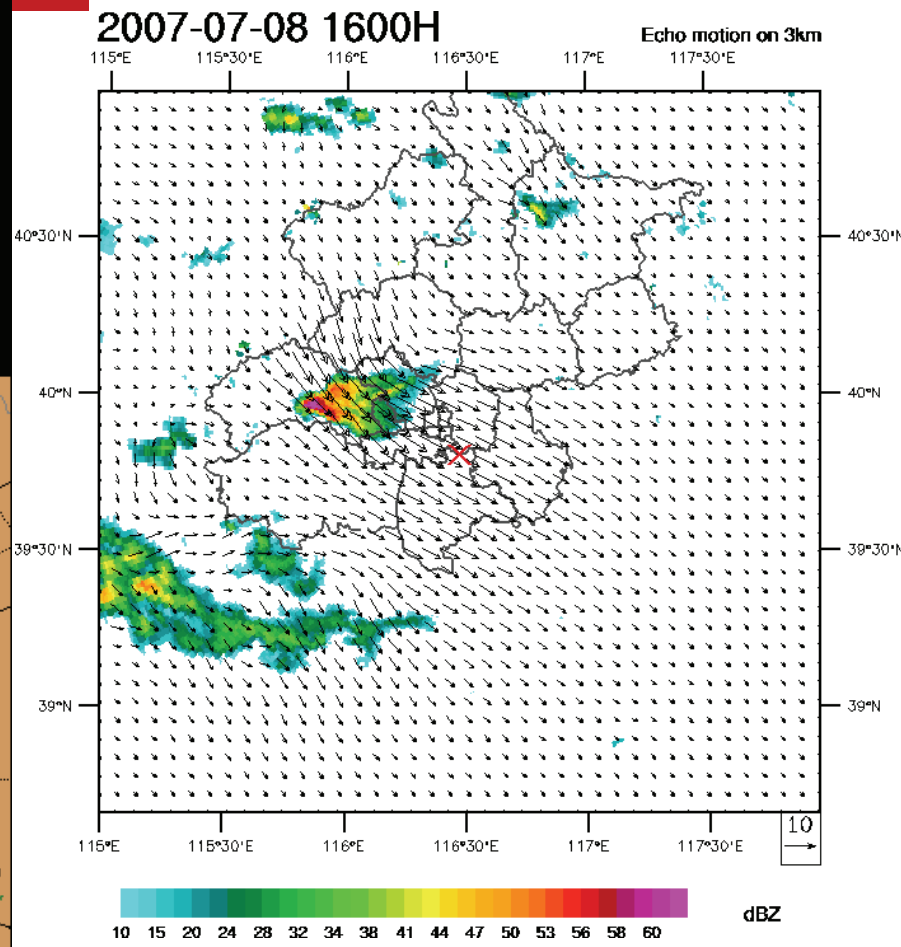




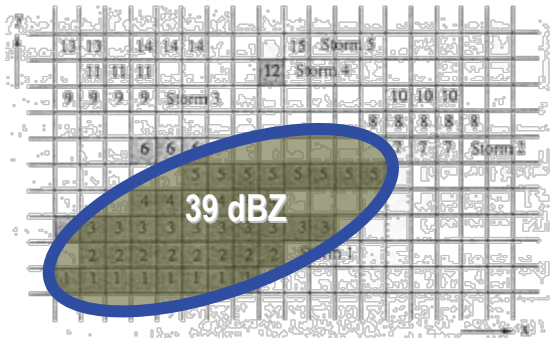
In this case MOVA, TREC and GTrack are all similar to each other

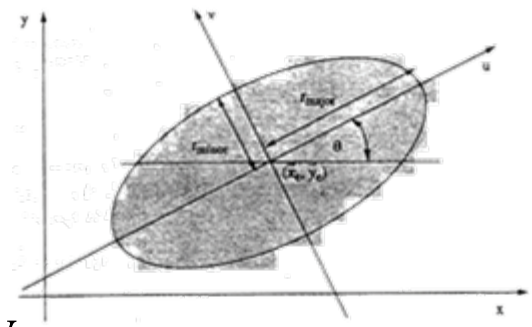
2007-07-08 16:00H



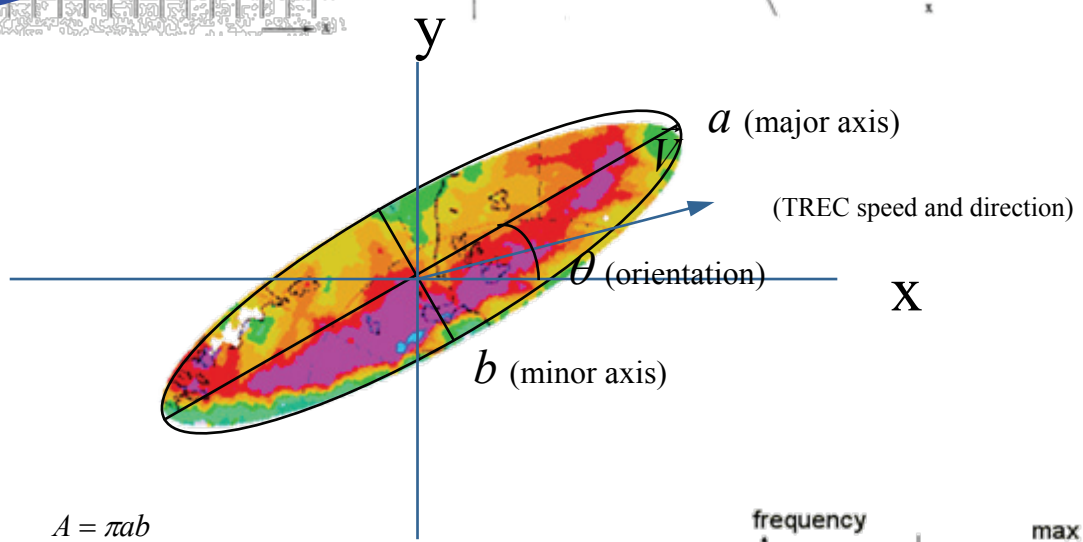


Storm Identification by "G-Track"





Group echo identification (similar to TITAN algorithm)



area $A = \pi ab$

eccentricity $\varepsilon = \sqrt{a^2 - b^2} / a$

perimeter $P = 4aE(\pi/2, \varepsilon)$

orientation $\theta = \tan^{-1}(b/a)$

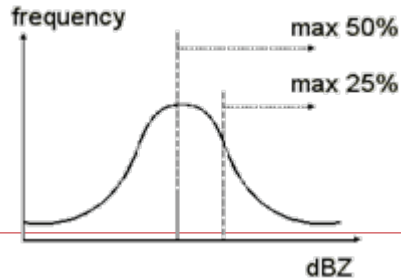
total intensity $I = \sum_{ellipse} dbZ \times \Delta A$

max dBZ <--> max rainfall

ave dBZ <--> ave rainfall

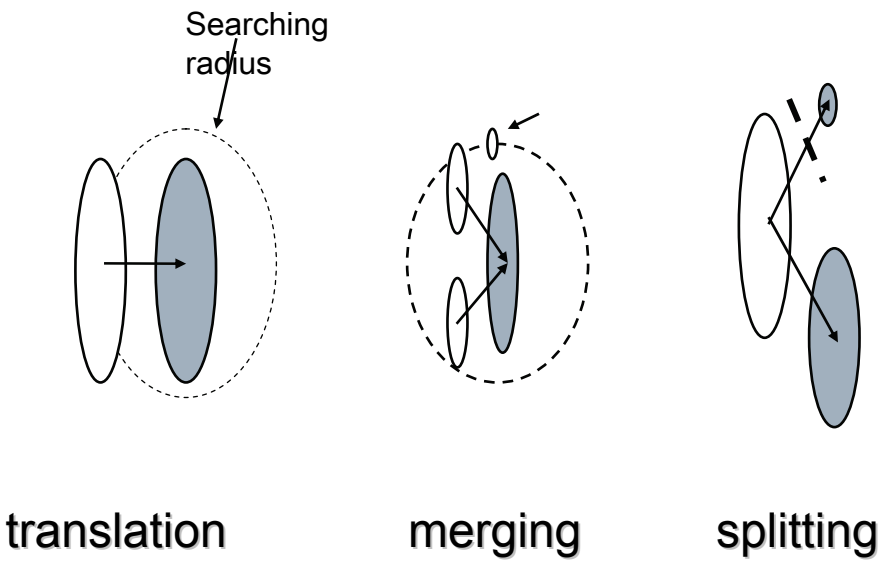
ave (max50% rainfall)

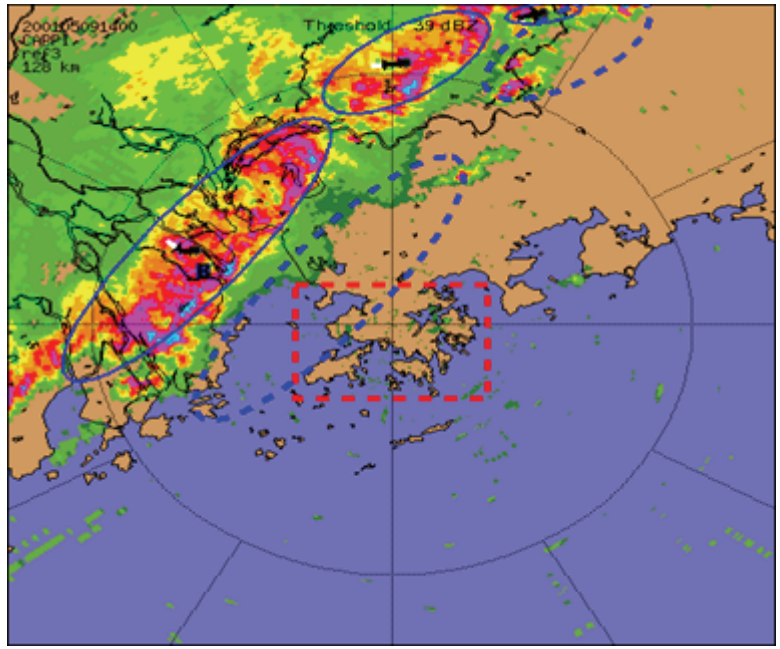
ave (max25% rainfall)



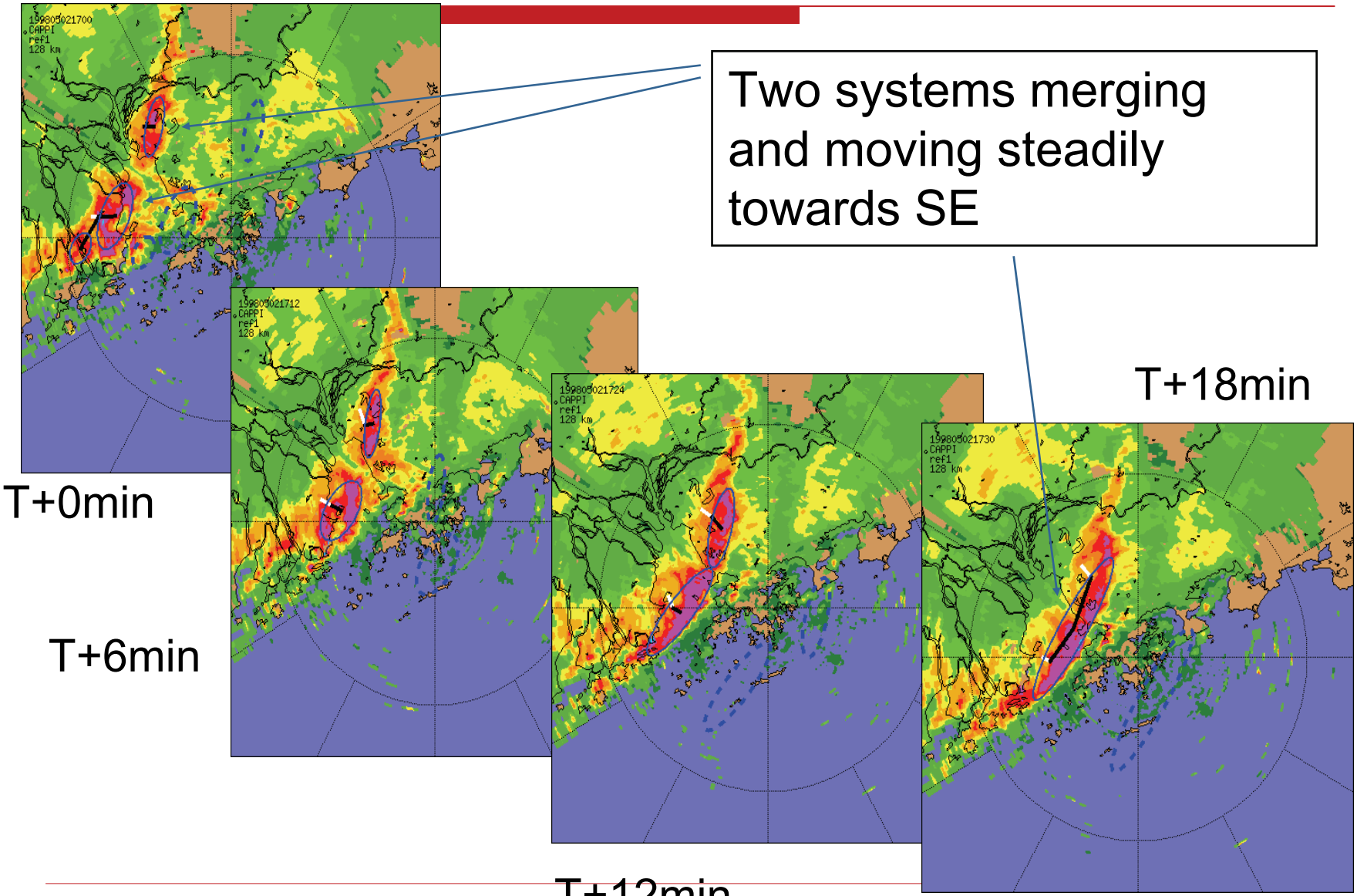
Tracking Capabilities

Based on moving speed, size, overlapping area





Case of G-Track forecast of a squall-line



Two systems merging and moving steadily towards SE

T+0min

T+6min

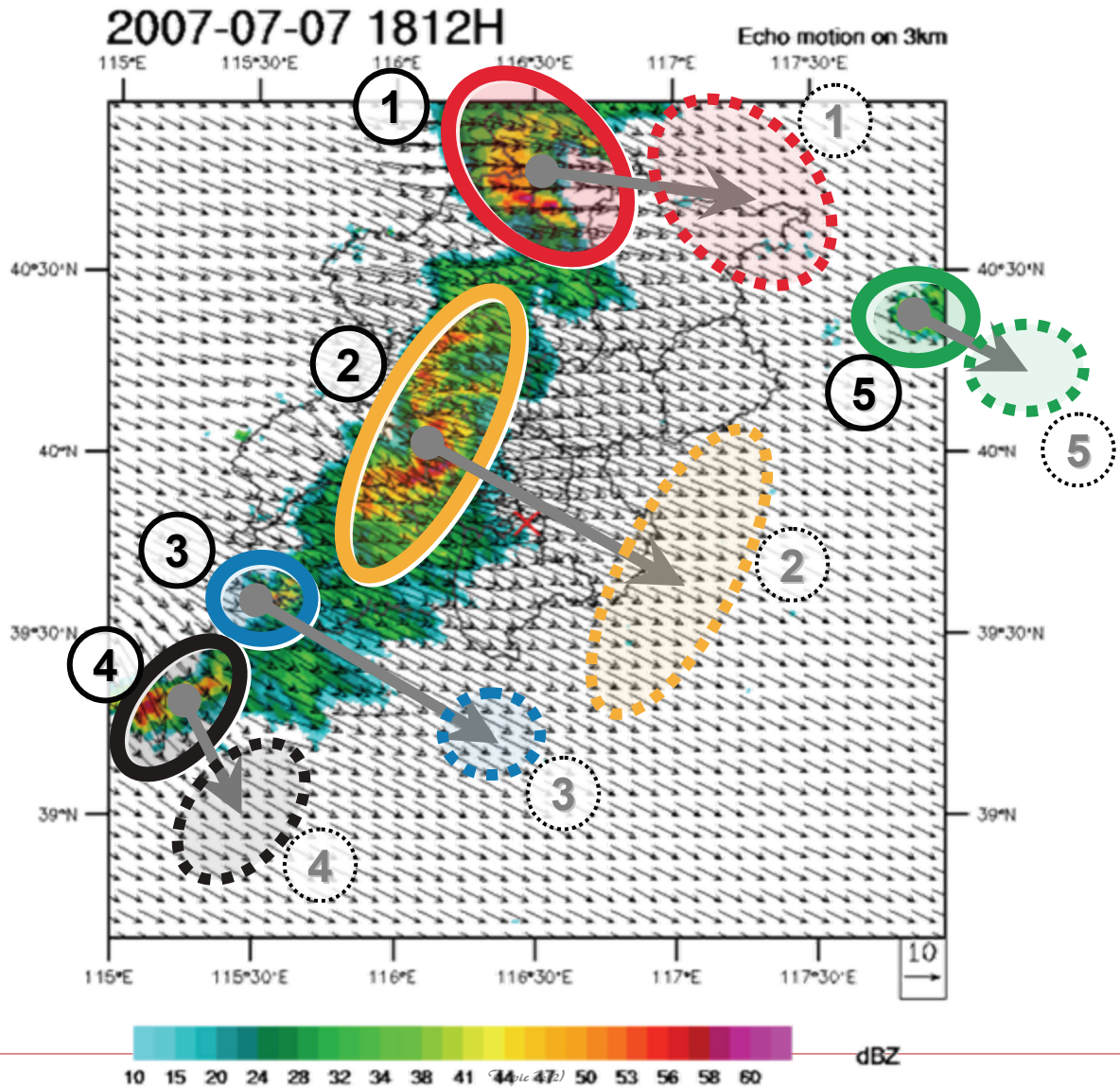
T+12min

T+18min

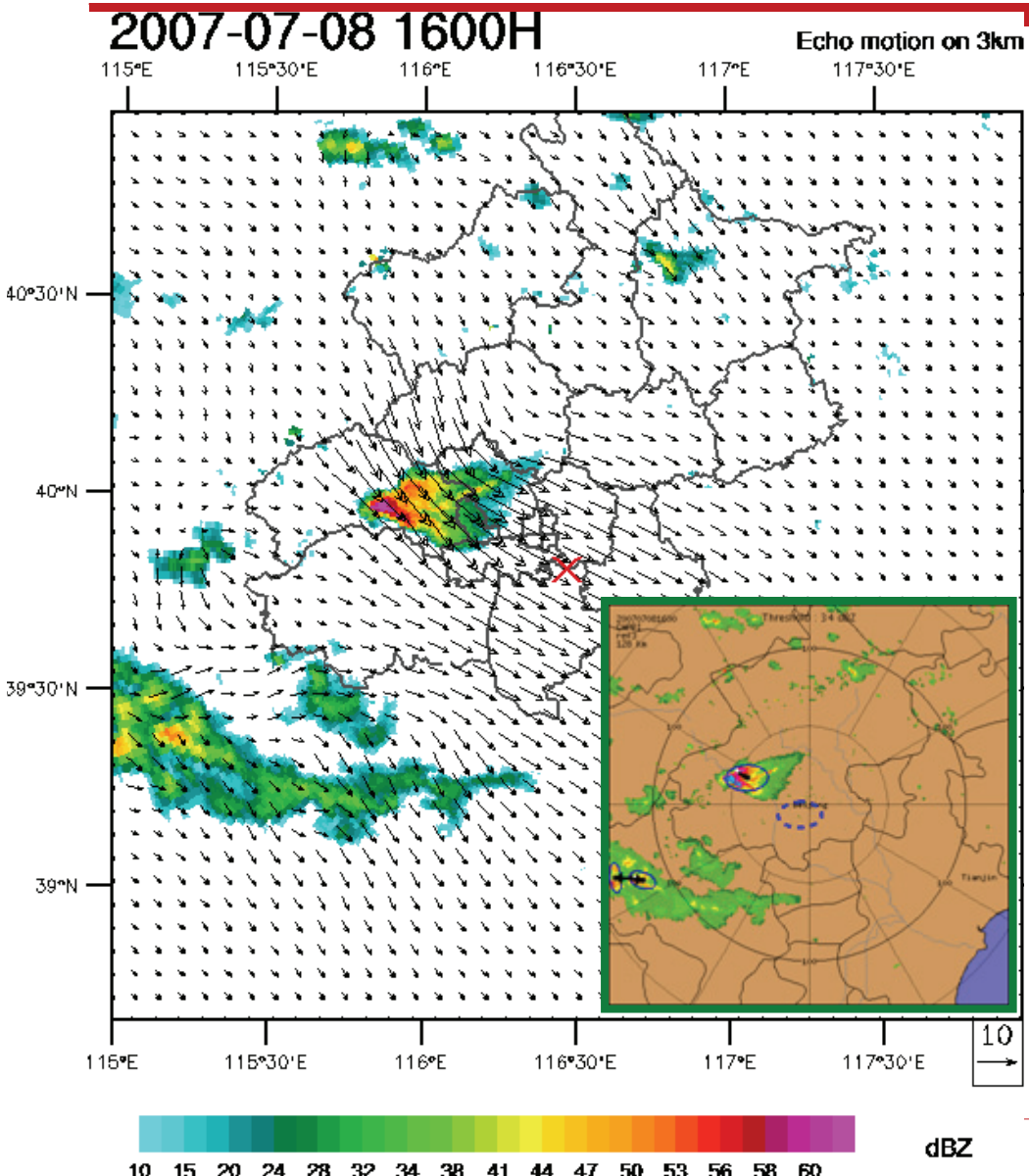
Difficulties with Centroid Tracking

- problematic tracking of cells undergoing split or merging
- large errors could result
  - *e.g. due to wrong direction*
- grid-based tracking offers a more robust tracking method
  - *and on average more accurate*

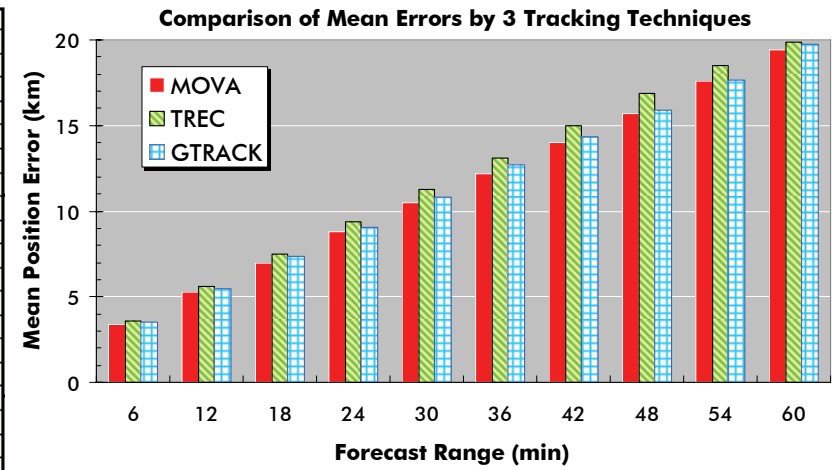
Storm Track f/c based on MOVA



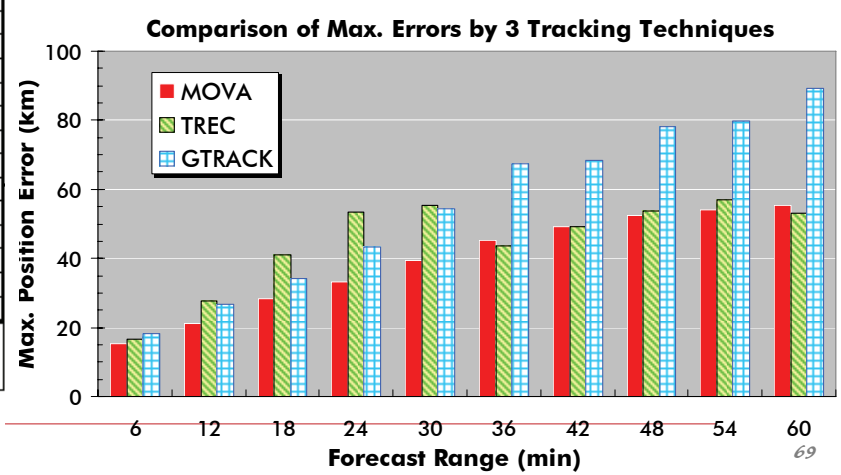
MOVA-based Storm Track f/c



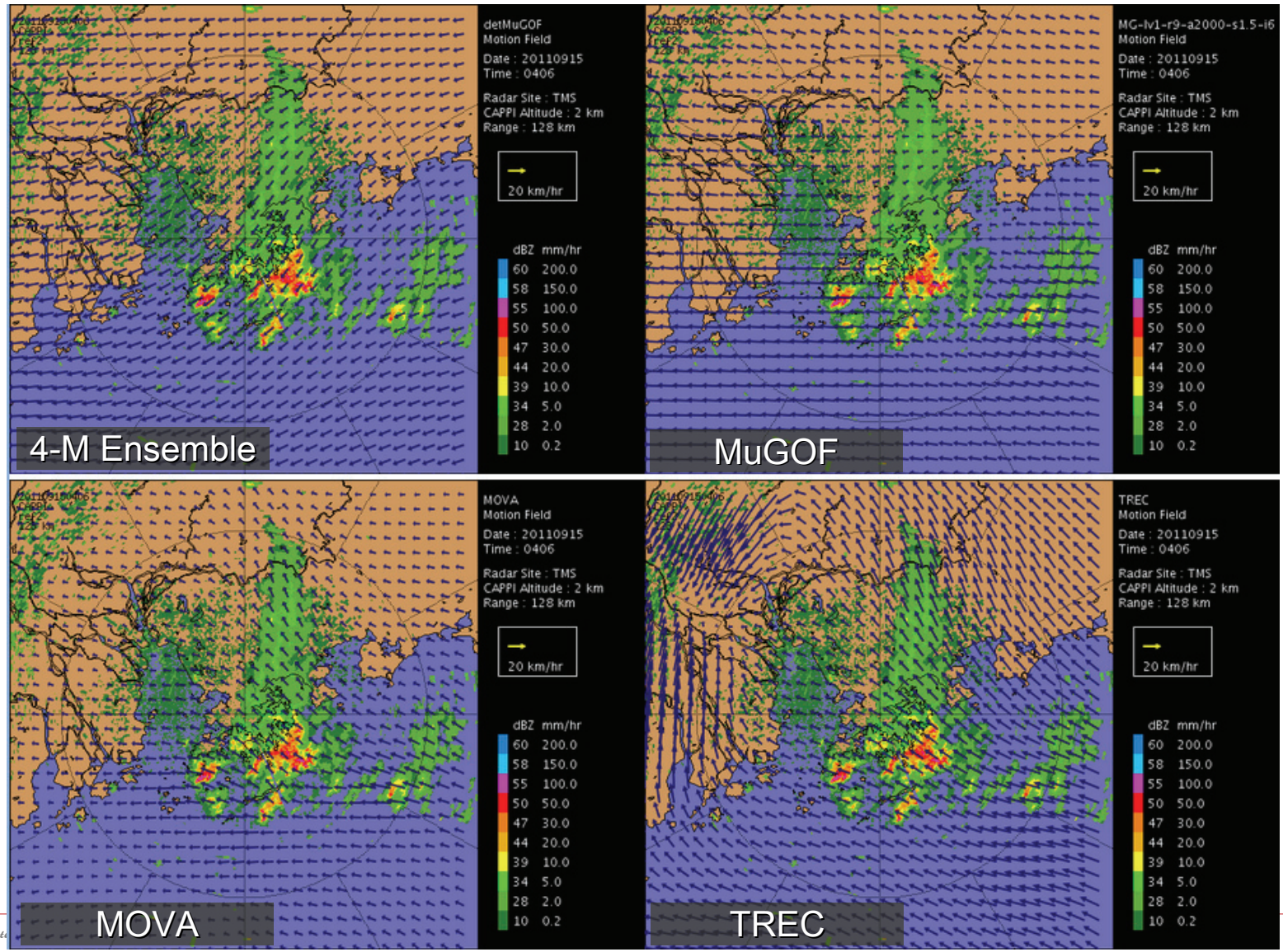
2007 trial



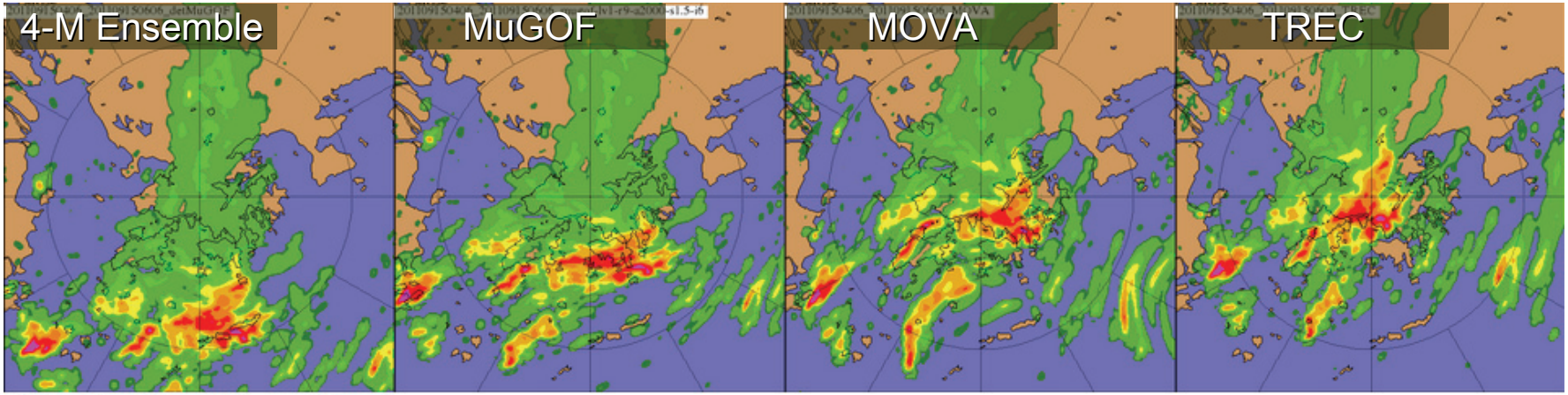
max. track error

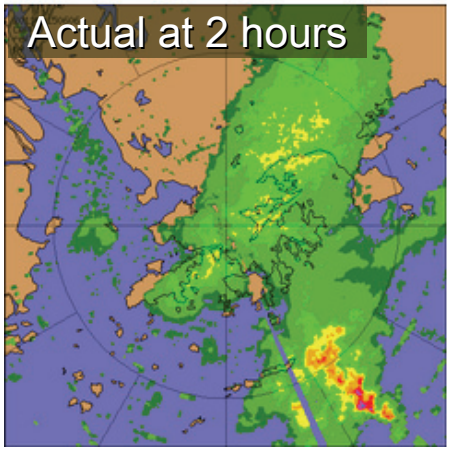


Challenge in Radar Tracking



Challenge in Radar Tracking





- two-hour forecast vs actual reflectivity
- uncertainty in motion field due to rapid development in thunderstorm

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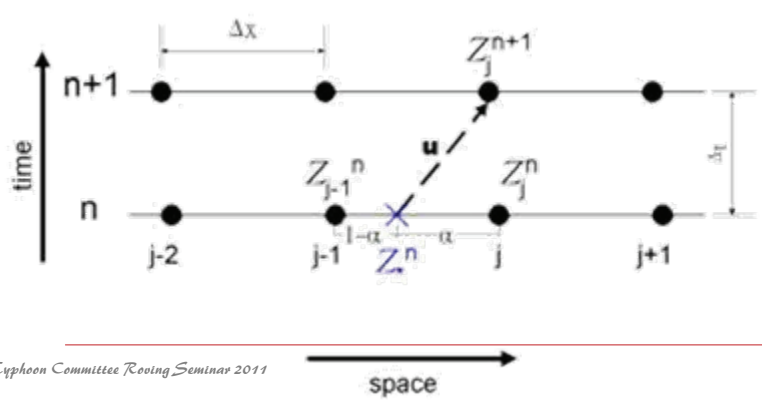
Non-Linear Extrapolation

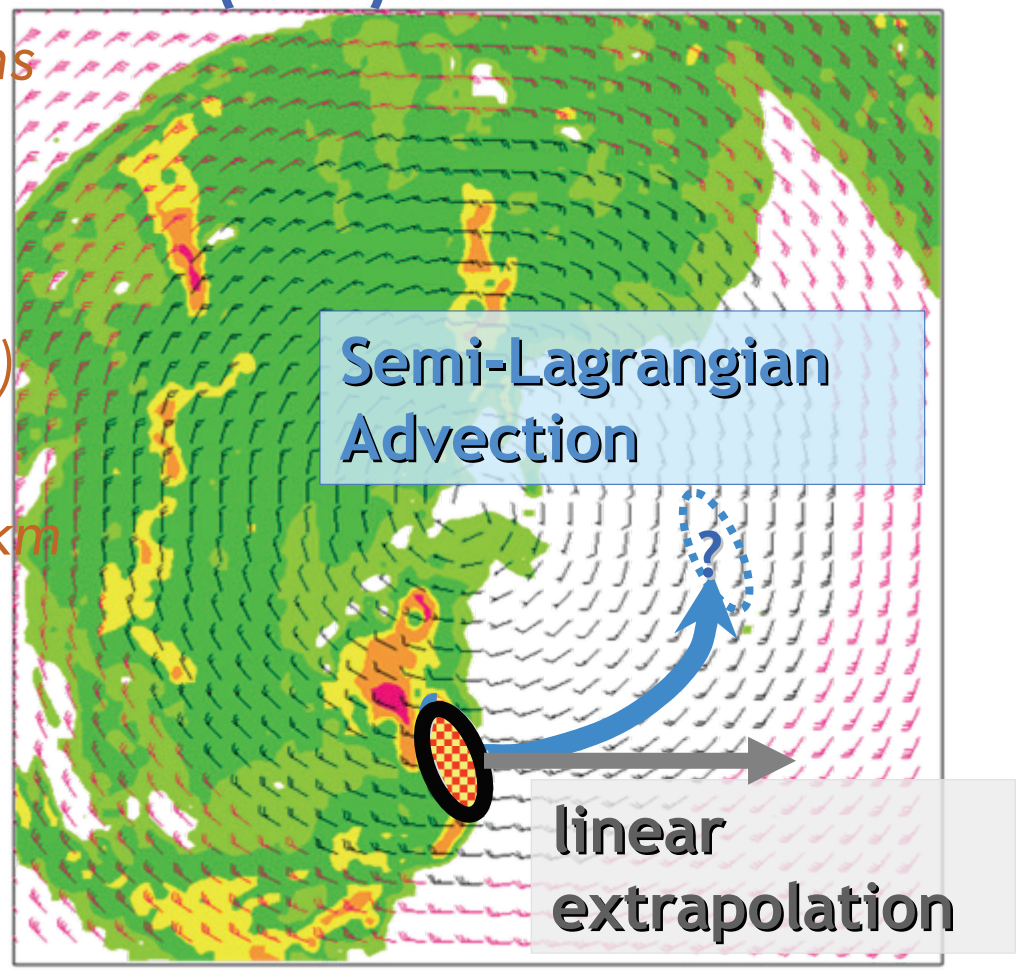
Forecast by Extrapolation

Semi-Lagrangian Advection (SLA)

$$\frac{dZ}{dt} = \frac{\partial Z}{\partial t} + \mathbf{u}\frac{\partial Z}{\partial x} = 0$$

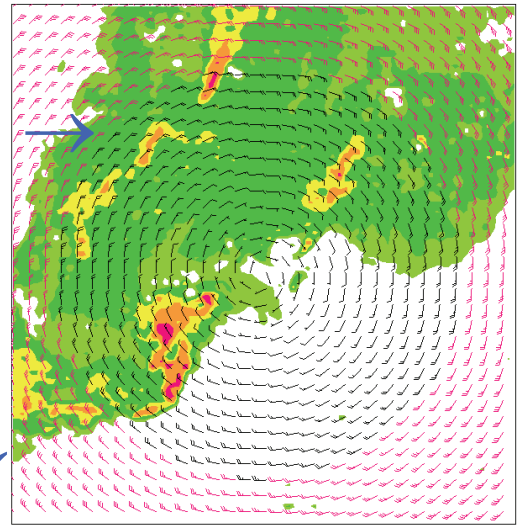
- Robert scheme (3 iterations to find origin point)
- Bi-cubic interpolation
- Flux limiter (local max, min constraint)
- One-way nesting
- resolution 1.1 km -> 0.5 km



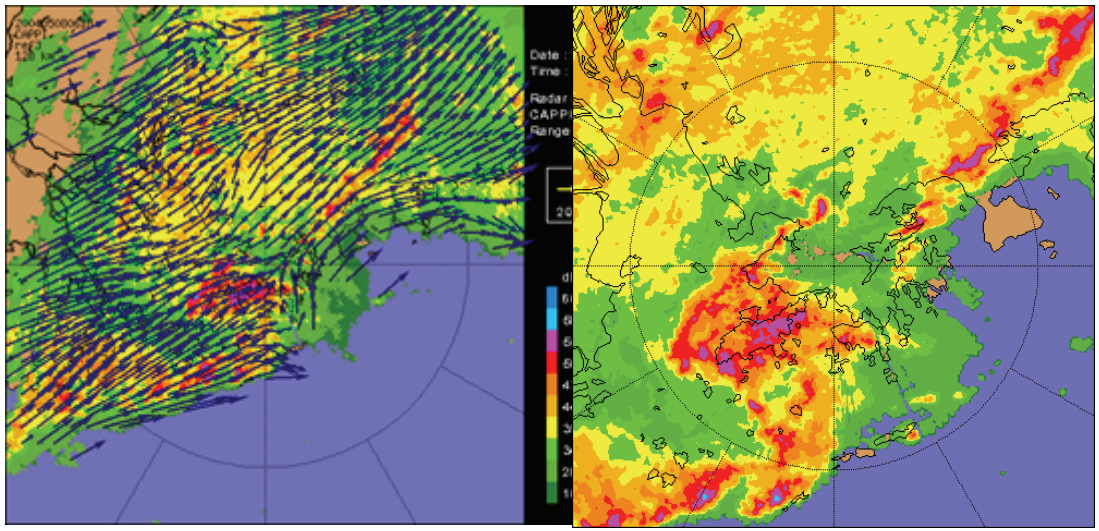


SWDRLS SLA Examples

- circulation pattern preserved →
- numerically less dissipative ↓



Forecast reflectivity – pure rotation
Up to 6 hr (6-min interval)

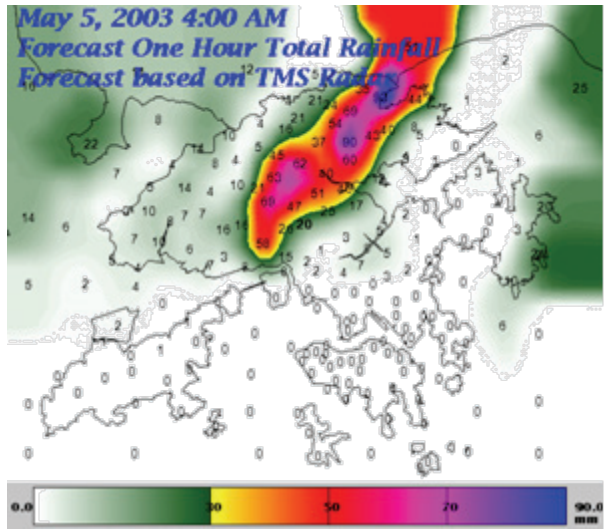


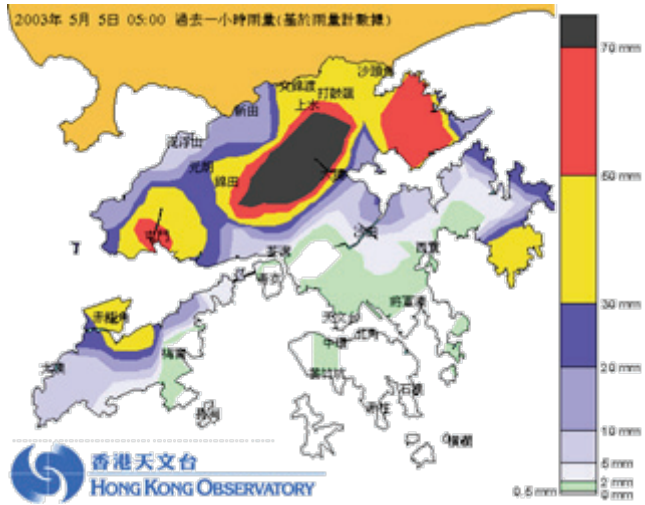
TREC wind

Forecast reflectivity – TREC wind
Up to 6 hr (6-min interval)

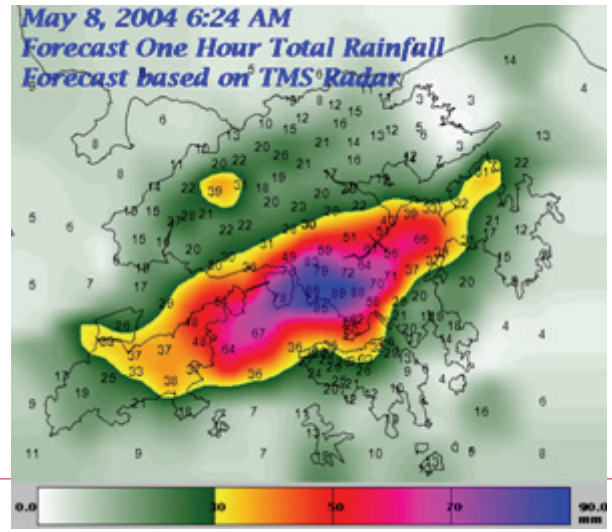
Real Cases in 2003 & 2004 (by simple extrapolation)

- 5 May 2003
- SAF and Red RW
- SWIRLS 1-h fc (left)
- actual at 5 am (right)





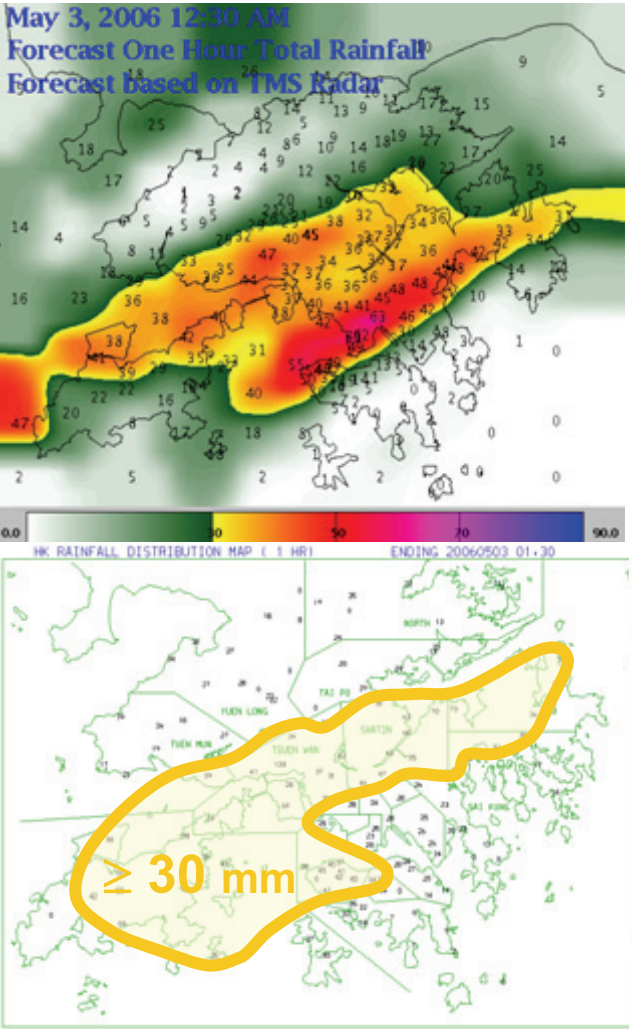
- 8 May 2004
- Black RW
- SWIRLS 1-h fc (left)
- actual at 7:25 am



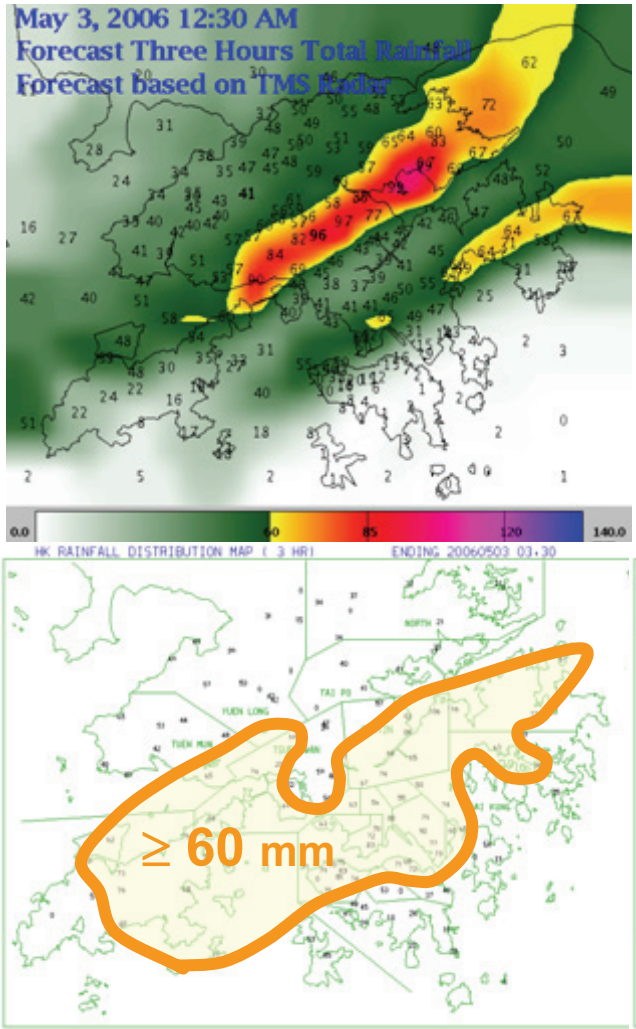
Real Case in 2006 (by SLA)

- 3 May 2006
- Red RW, Landslip & Flooding
- SWIRLS (top), actual (bottom)

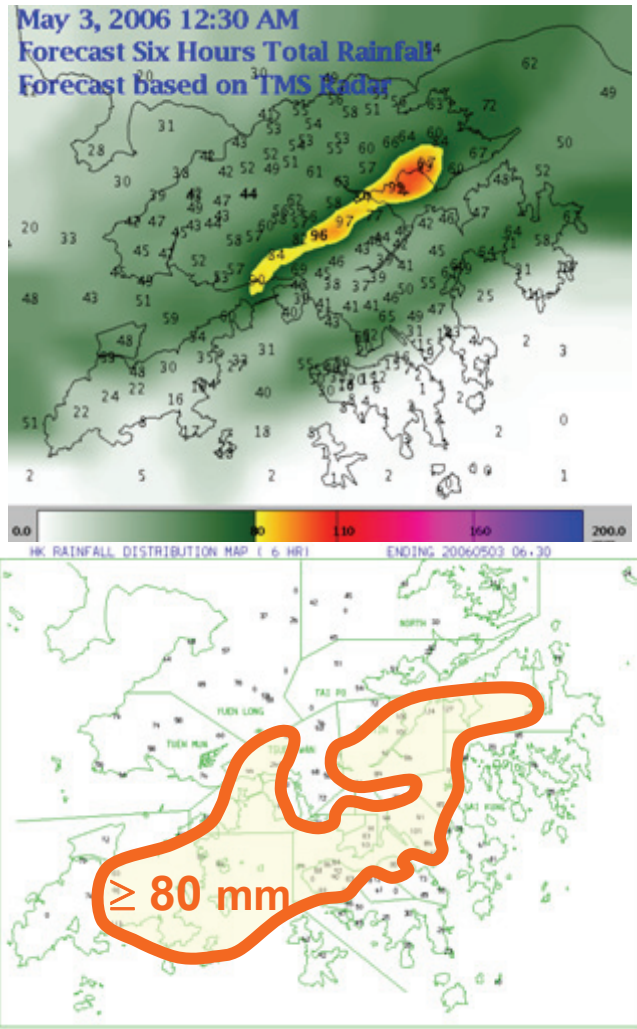
1-hour



3-hour



6-hour



Some Reflections

- nowcast is good for advective type of rain events with intensity up to, say 30 mm/h
  - *reflected in a high CSI for Amber*
- for more extreme rainfall, rapid development of rain cells are usually involved and nowcast loses skill
  - *reflected in the low CSI of Red and Flood*
- How to do better? with longer lead?
  - *consider blending with NWP QPF*

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ESCAP

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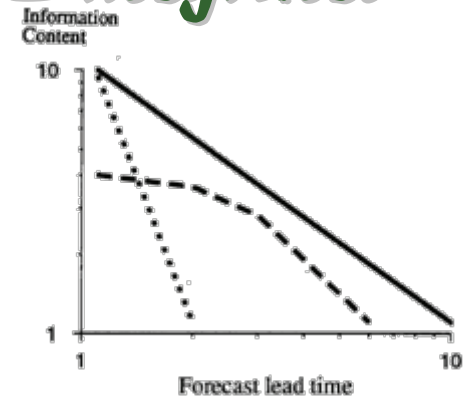
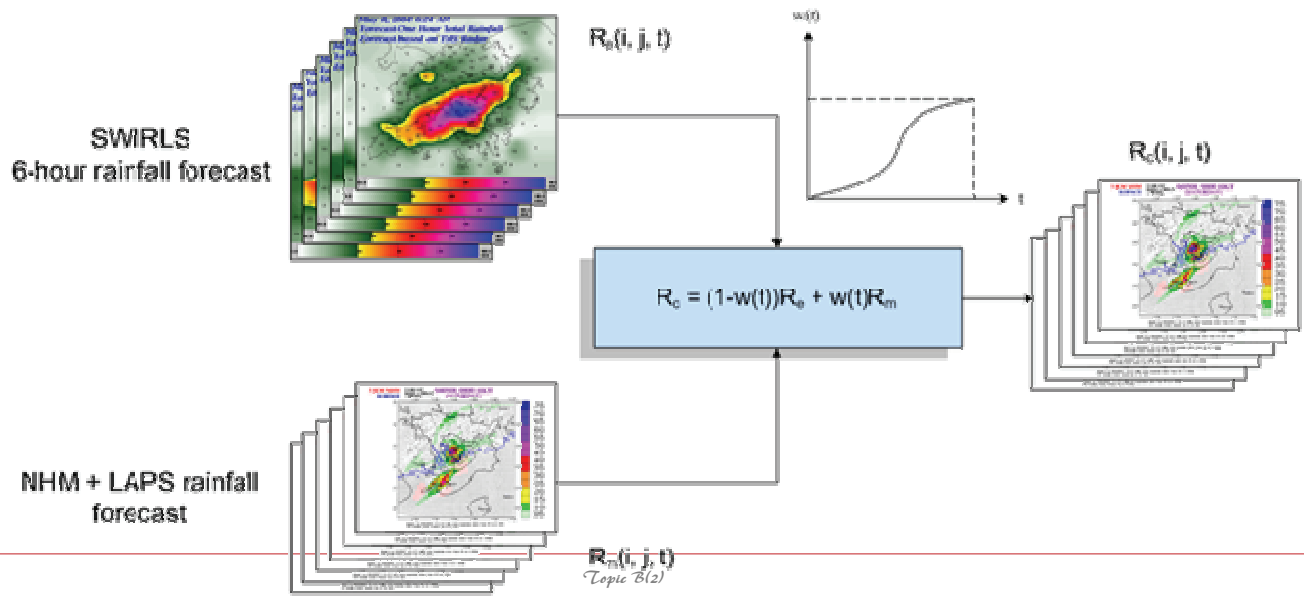
Blending of QPFs

RAPIDS

(Rainstorm Analysis and Prediction Integrated Data-processing System)



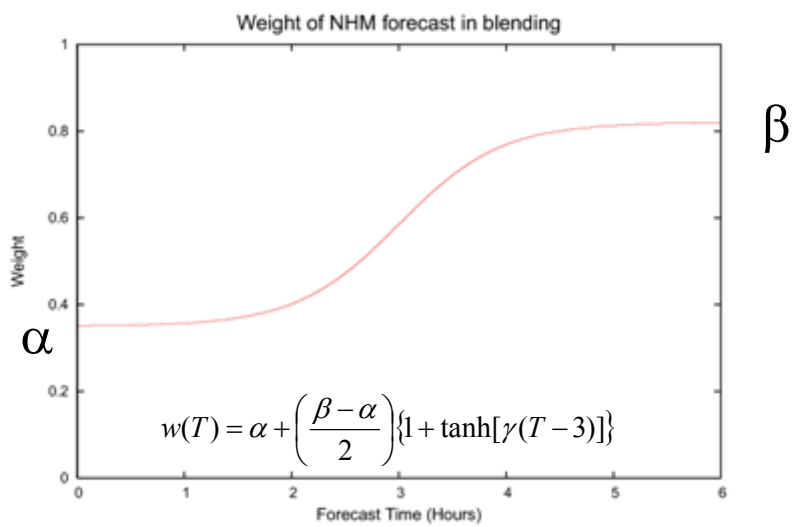
- to provide 1-6 hours blended QPF
- 2-km resolution, hourly/6-min updating
- NOWCASTING component – SWIRLS
  - *QPF by semi-Lagrangian advection of radar echoes*
- NWP component – NHM
  - *QPF by non-hydrostatic model*



Blending SWDRLS with NHM QPF

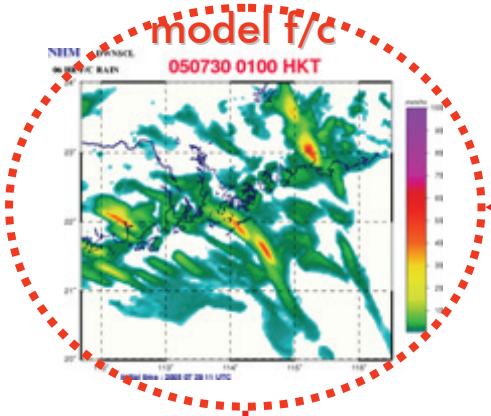
$$QPF(t) = (1 - w(t)) \times QPF_{SLAS} + w(t) \times QPF_{NHM}$$

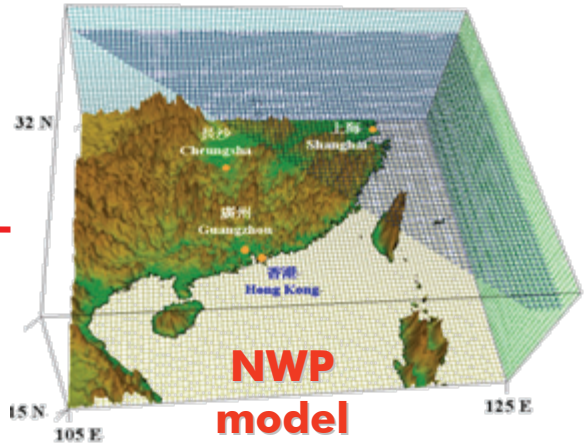
Dynamical blending –
hyperbolic function with varying end points



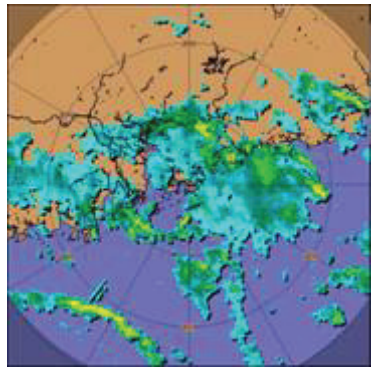
α, β determined dynamically by past performance

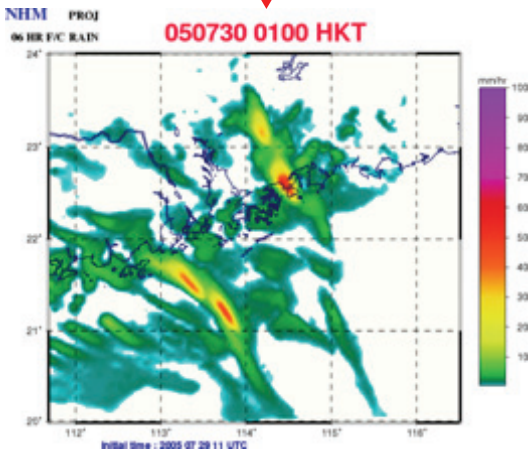
Merging Nowcast with NWP



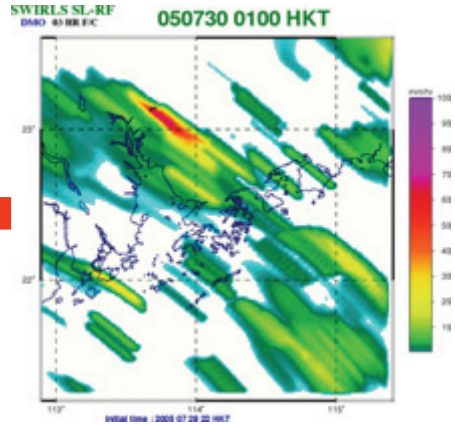


Radar

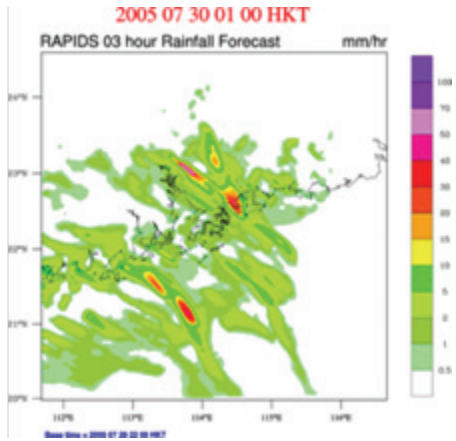




Phase-corrected Model QPF



SWIRLS QPF



RAPIDS QPF

Phase correction based on MOVA

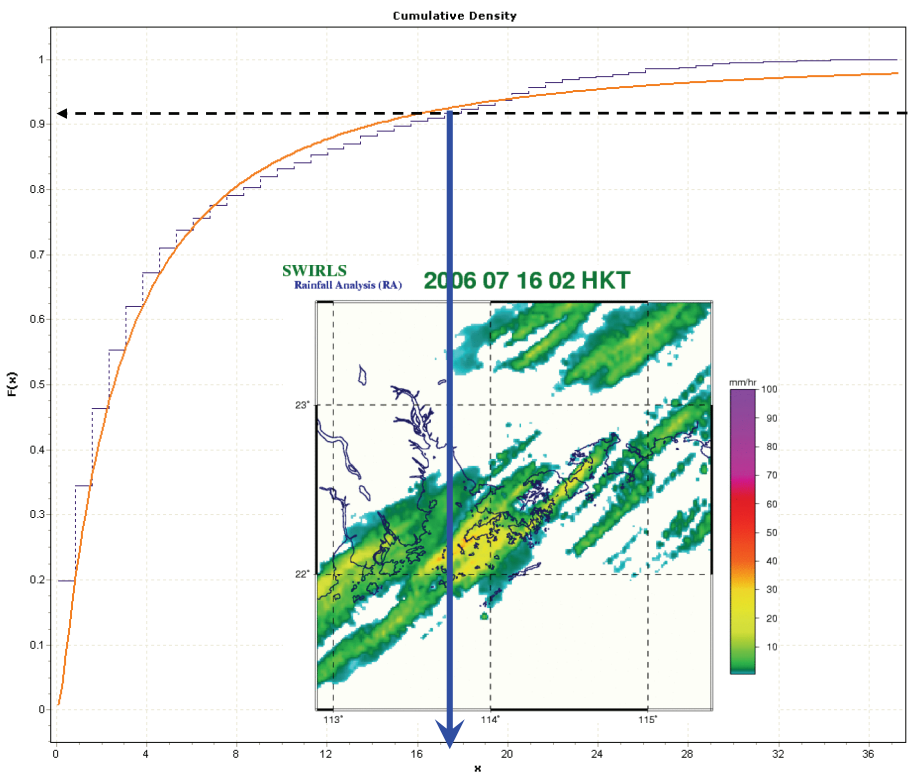
- Given NHM QPF and SWIRLS Rainfall Analysis valid at same forecast time:

$$\min: \quad J = \iint \left[\frac{\partial I}{\partial t} + u \frac{\partial I}{\partial x} + v \frac{\partial I}{\partial y} \right]^2_{NHM \rightarrow SWIRLS} dxdy$$

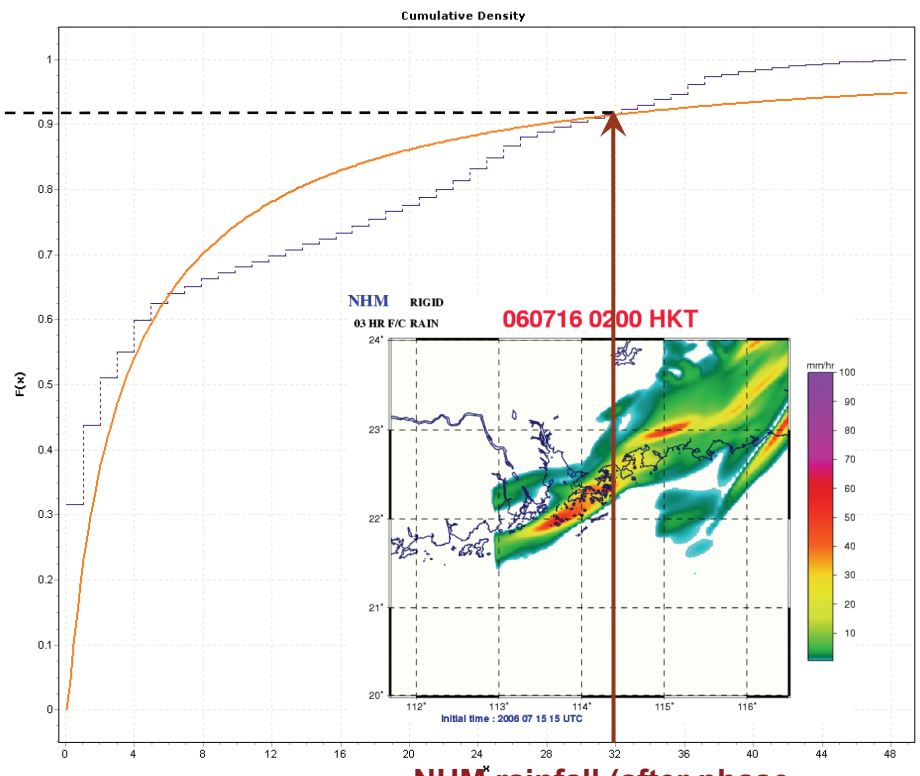
- A 10x10 block is used in regional phase correction

Calibration of NHM rainfall intensity

- To match with the frequency distribution of SWIRLS rainfall analysis



Calibrated NHM rainfall according to cdf of SWIRLS rainfall analysis

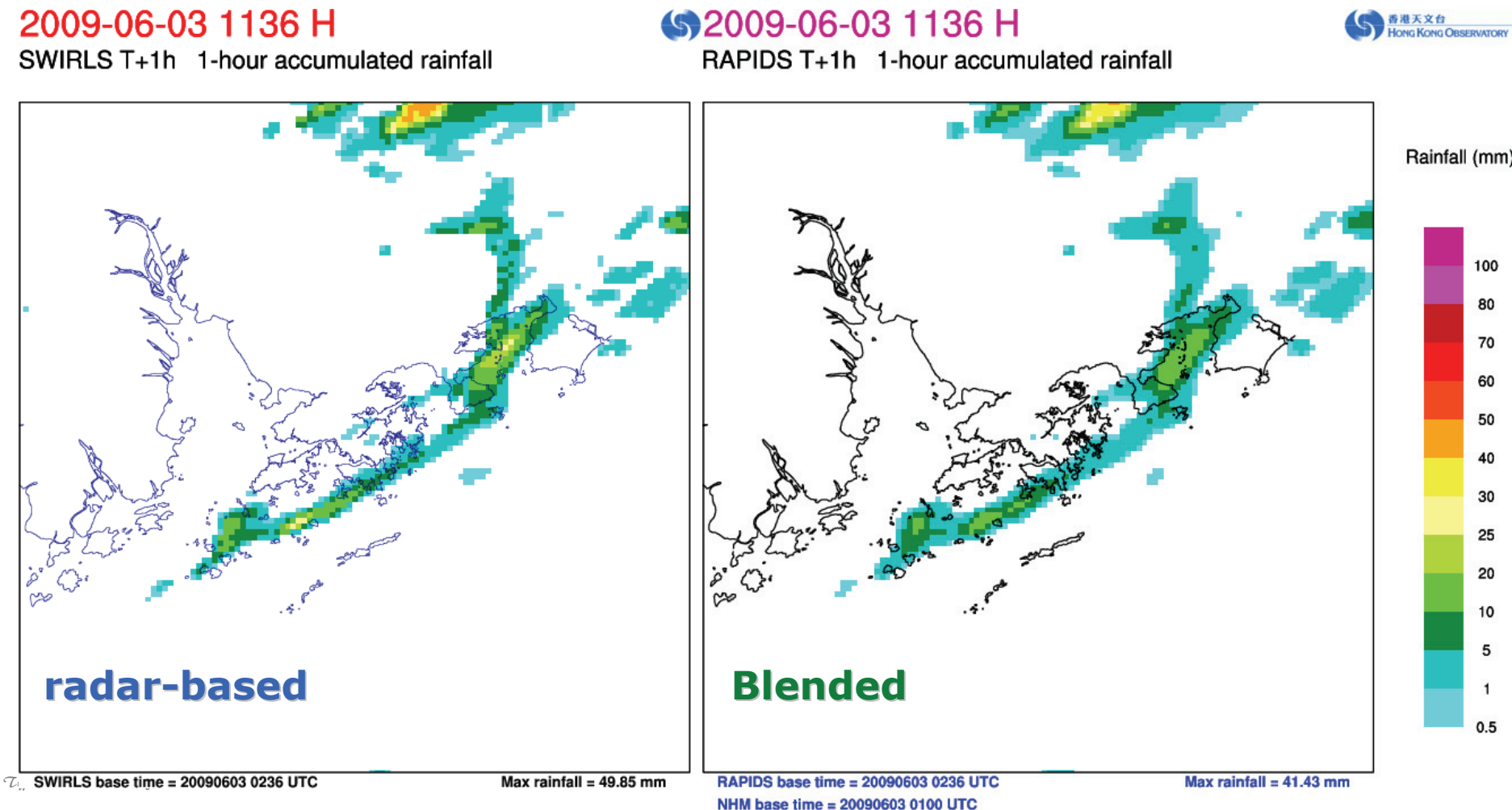


NHM rainfall (after phase correction) at grid point (x,y)

N.B. can extend to include all rain grids over past few hours in order to get a 'smoother' calibration mapping

RAPIDS in Real Time

1-hour forecast

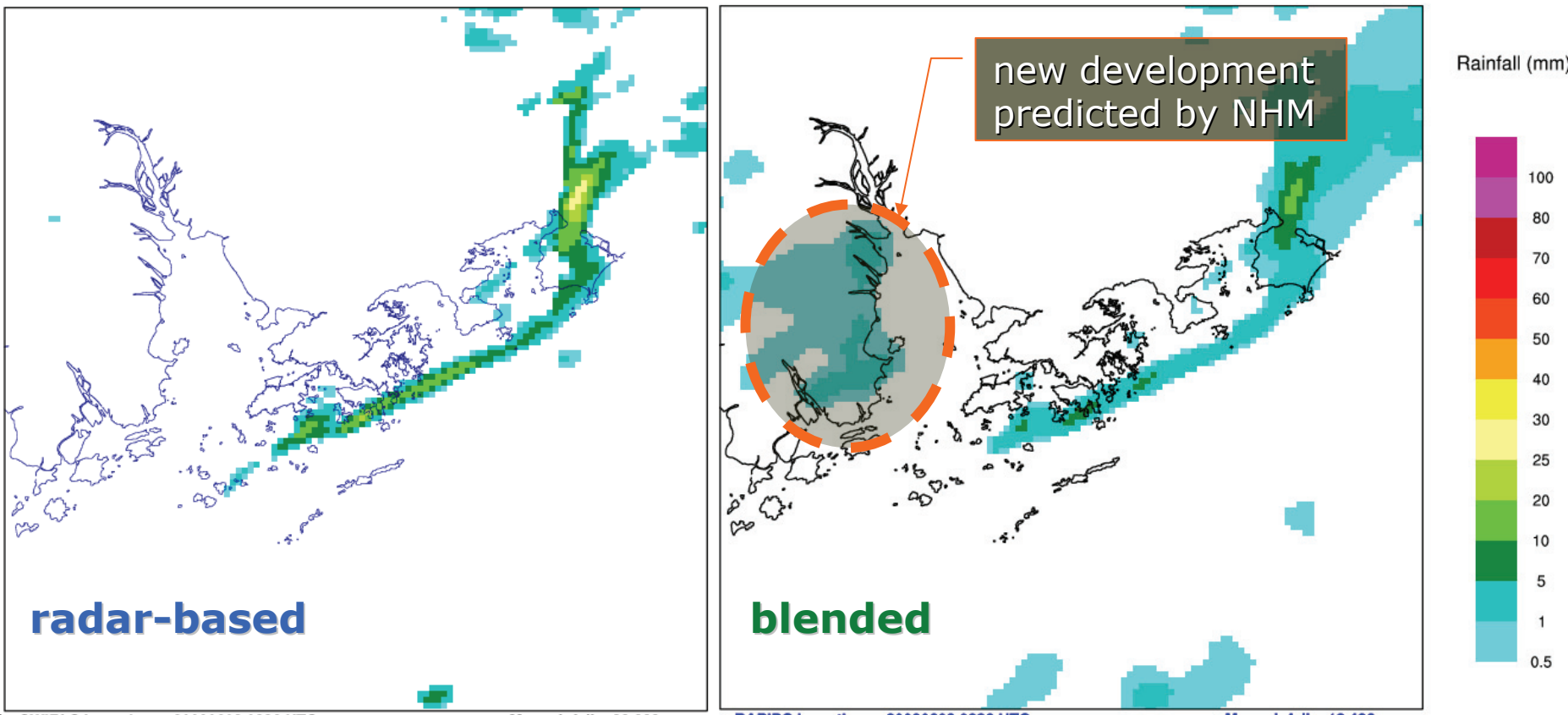


RAPIDS in Real Time

3-hour forecast

2009-06-03 1336 H
SWIRLS T+3h 1-hour accumulated rainfall

2009-06-03 1336 H
RAPIDS T+3h 1-hour accumulated rainfall

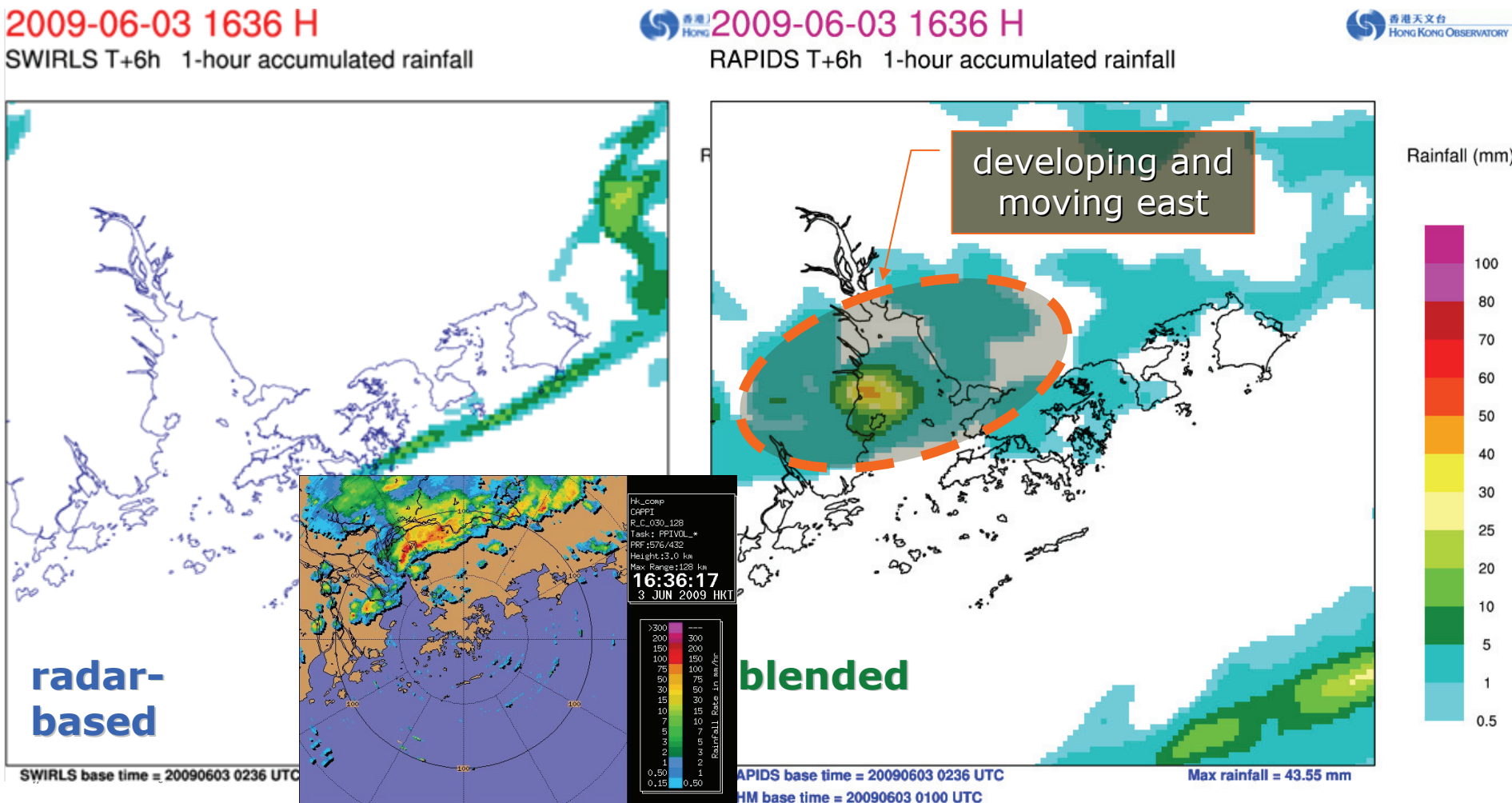


SWIRLS base time = 20090603 0236 UTC
Max rainfall = 28.662 mm

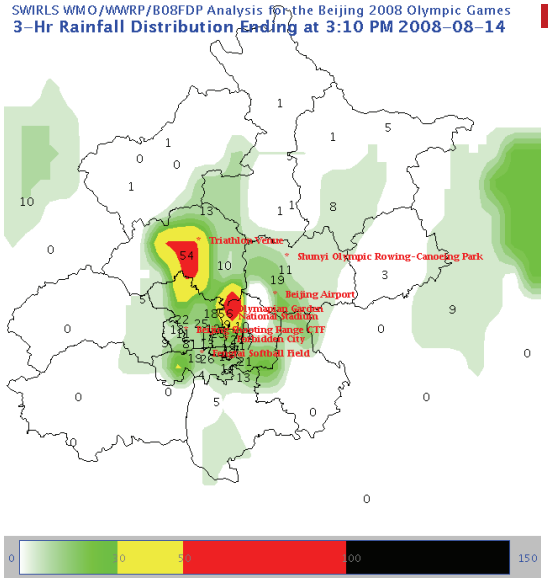
RAPIDS base time = 20090603 0236 UTC
NHM base time = 20090603 0100 UTC
Max rainfall = 12.436 mm

RAPIDS in Real Time

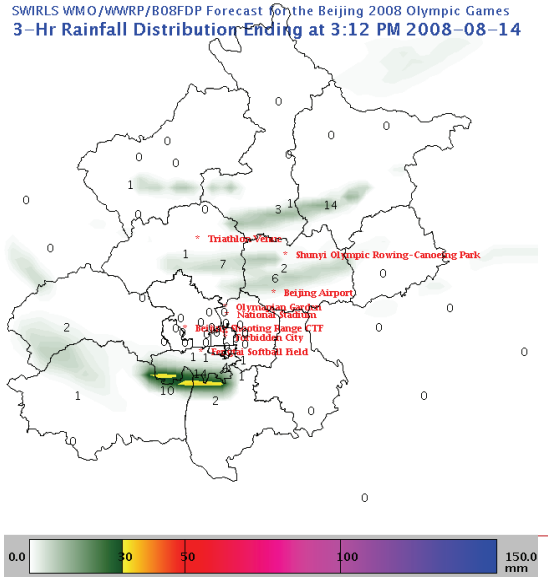
6-hour forecast



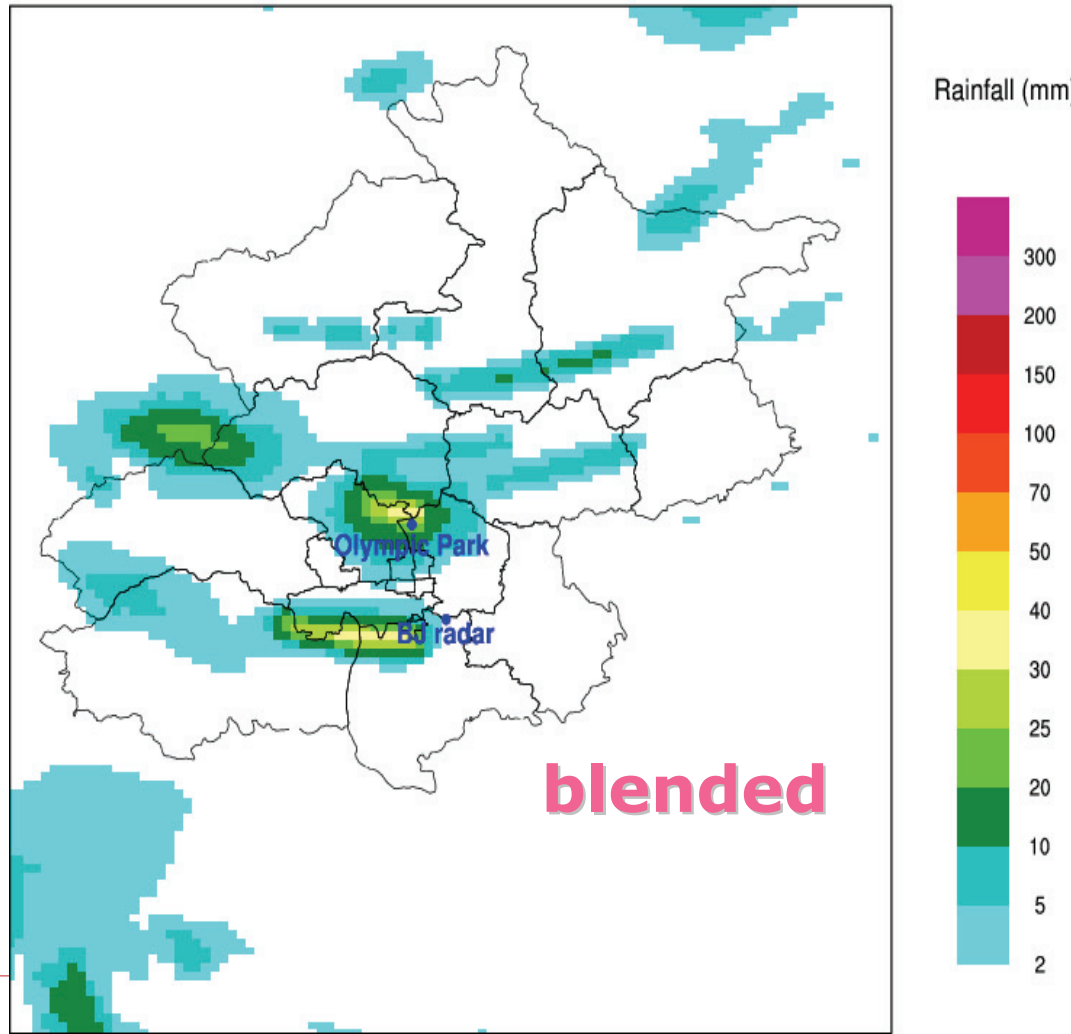
RAPIDS for Beijing



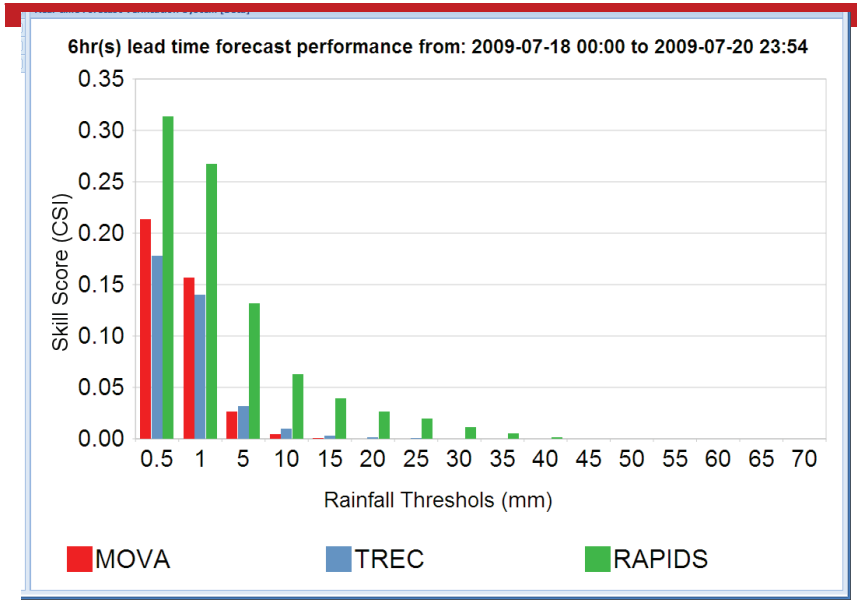
actual

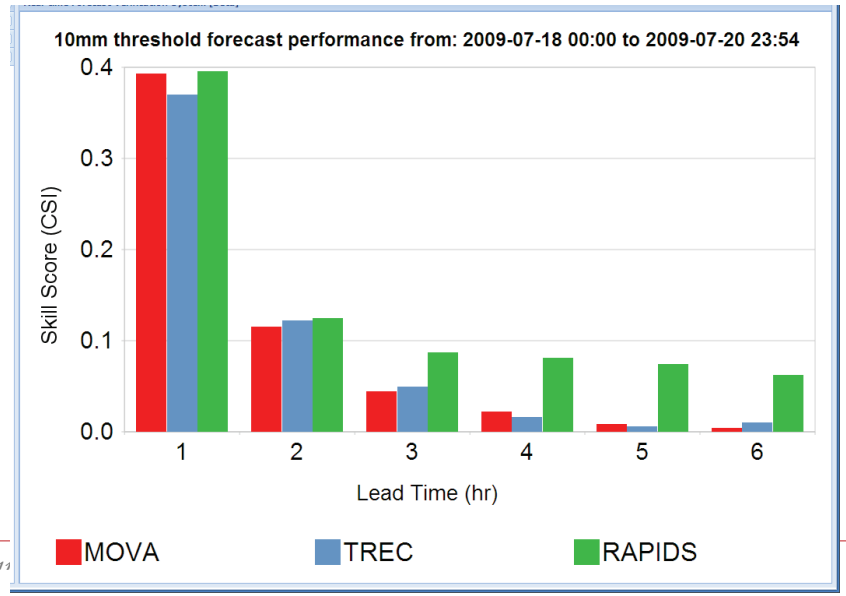


radar-based

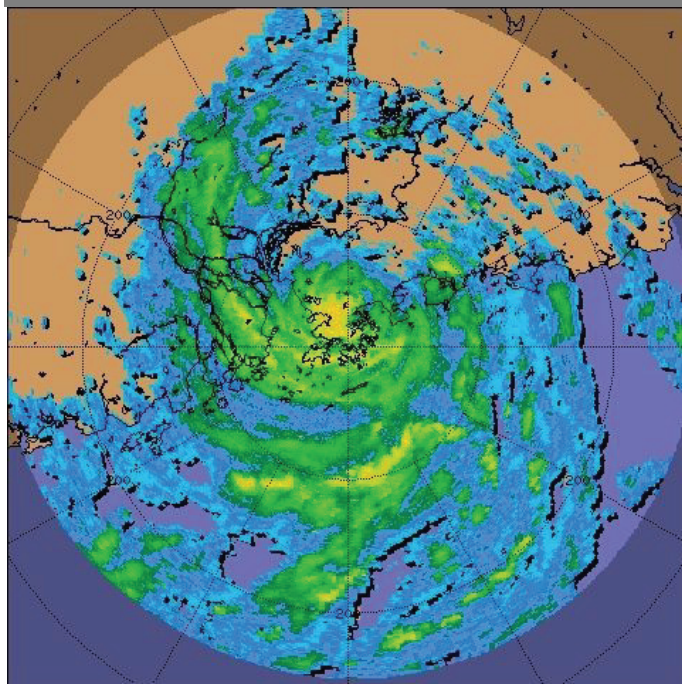


RAPIDS TC Performance





T. Molave



TOPS on SWORLS-2 QPF

- **for hourly rain or no rain f/c**
  - *nowcast QPF more skillful, especially in 1-3 hr*
  - *RAPIDS QPF approaching nowcast in 4-6 hr*
- **for hourly f/c of heavy rain (~ 30 mm/hr)**
  - *nowcast QPF more skillful in 1-2 hr*
- **for more extreme rainfall or longer lead**
  - *hourly QPF shows little skill*
  - *consider longer rainfall accumulations or probability*
- **for 3-6h rf accumulation**
  - *storm growth/decay is important*
  - *RAPIDS QPF out-performs nowcast up to, say 30mm*

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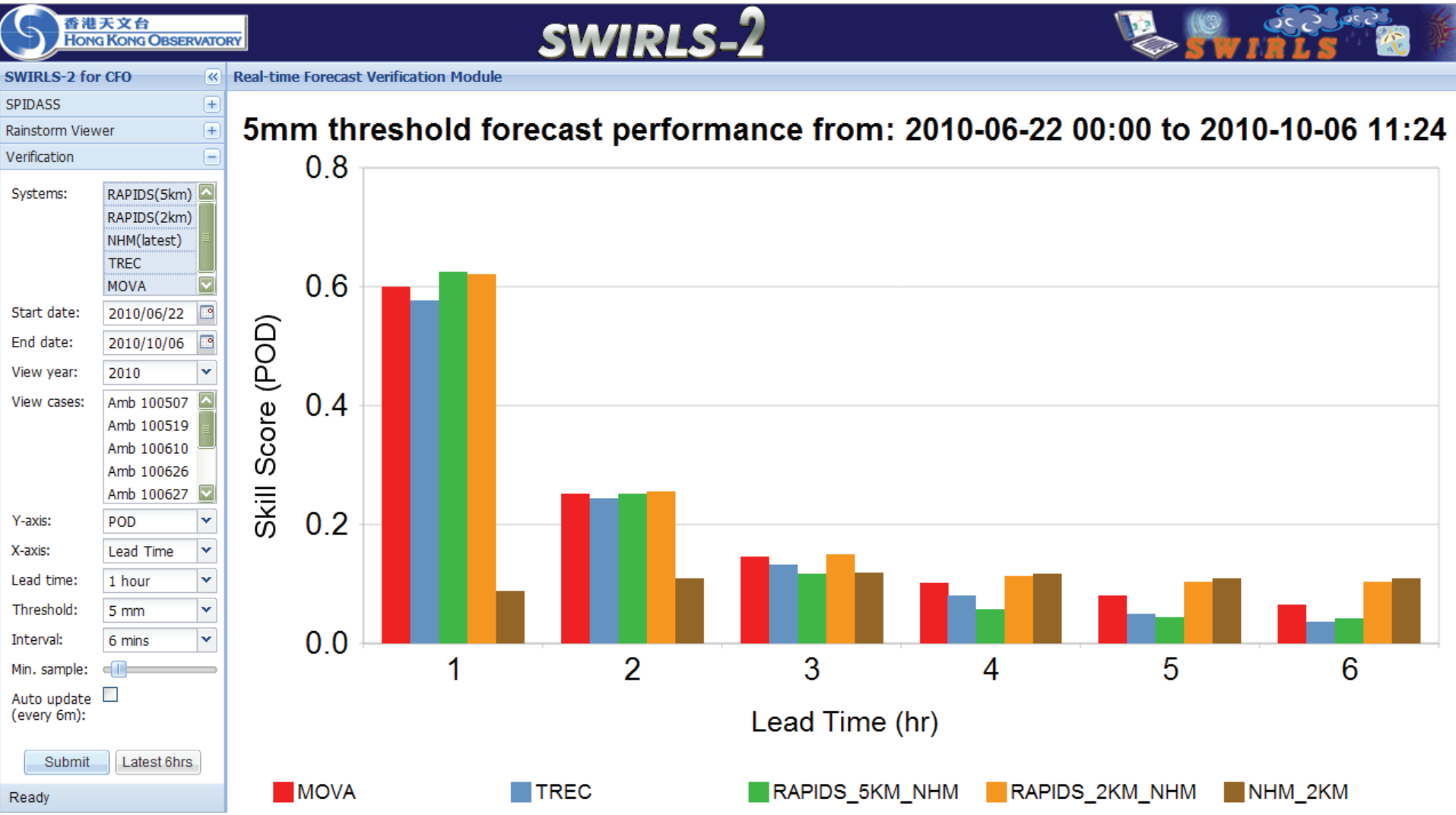
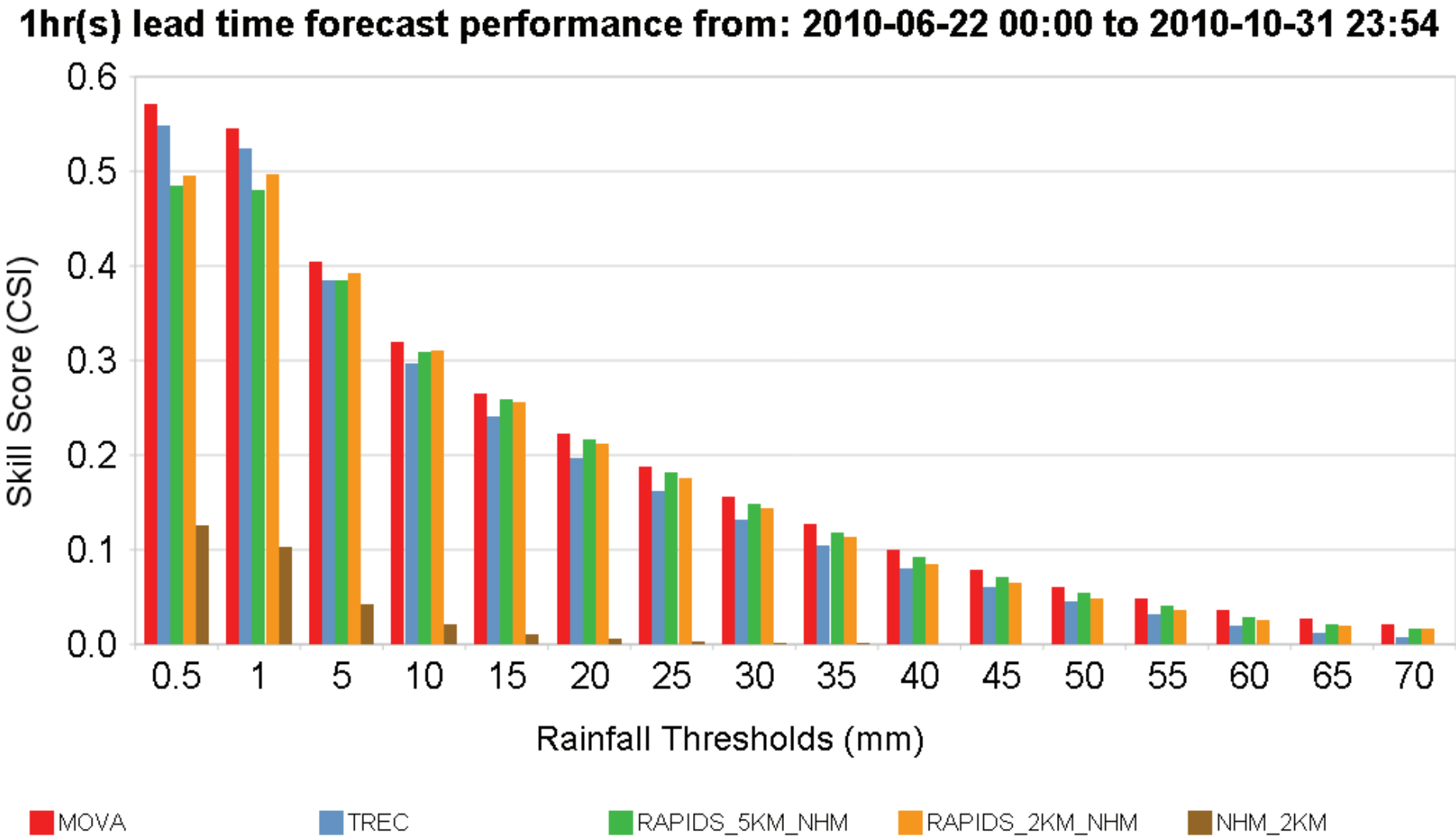
2PF Verification

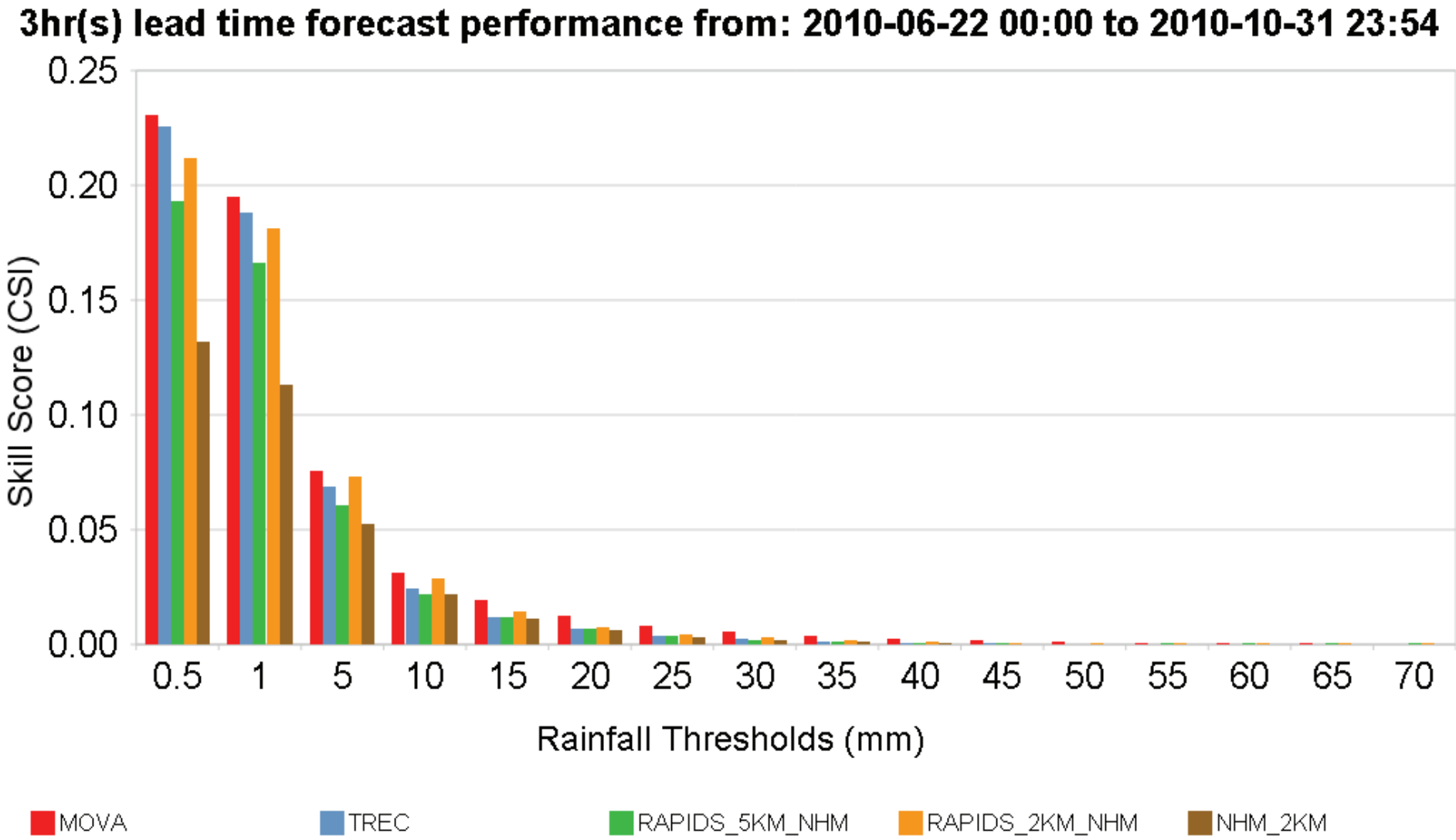
Preliminary Results



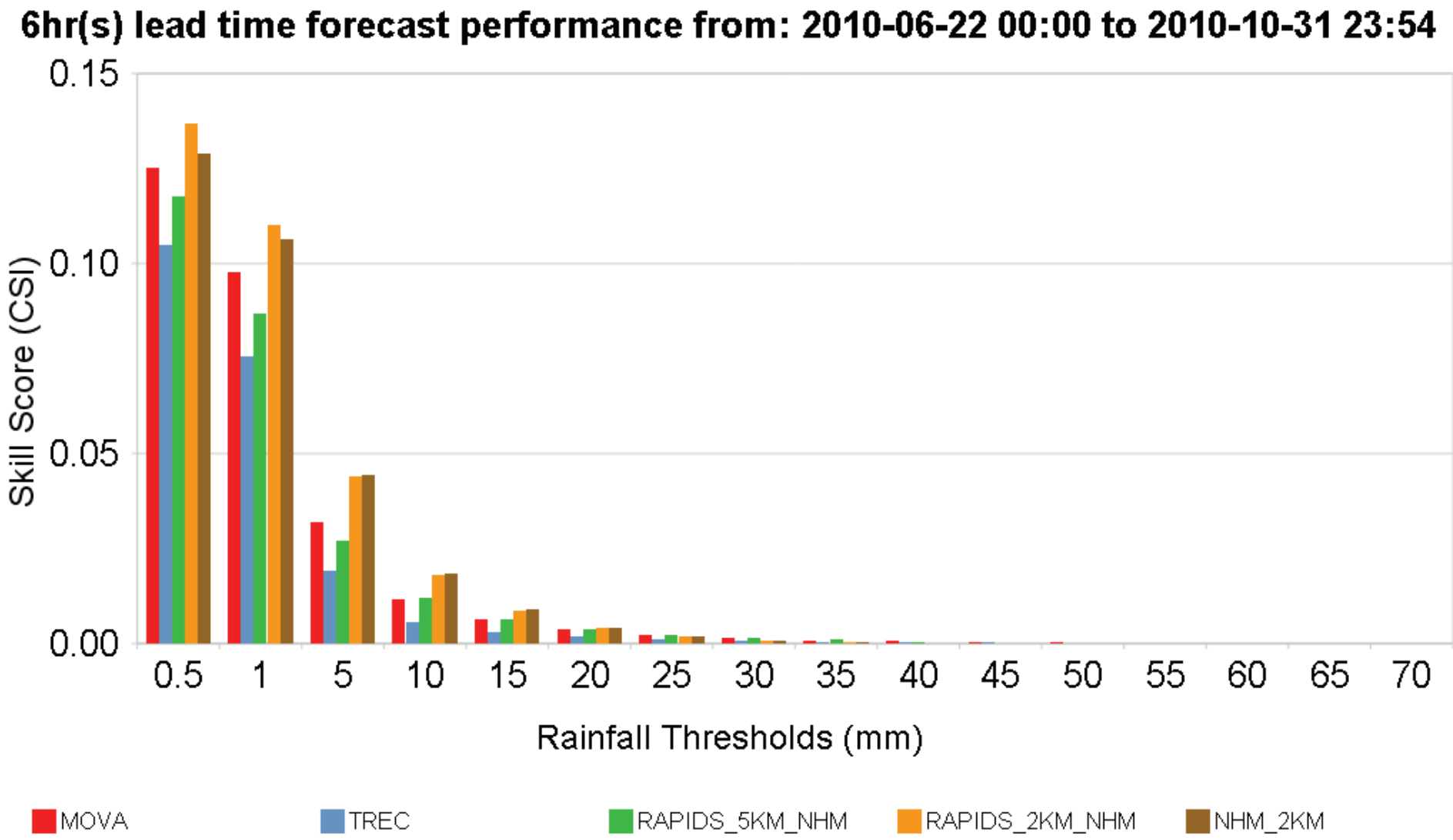
T+1h Performance



T+3h Performance



T+6h Performance



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~ End ~

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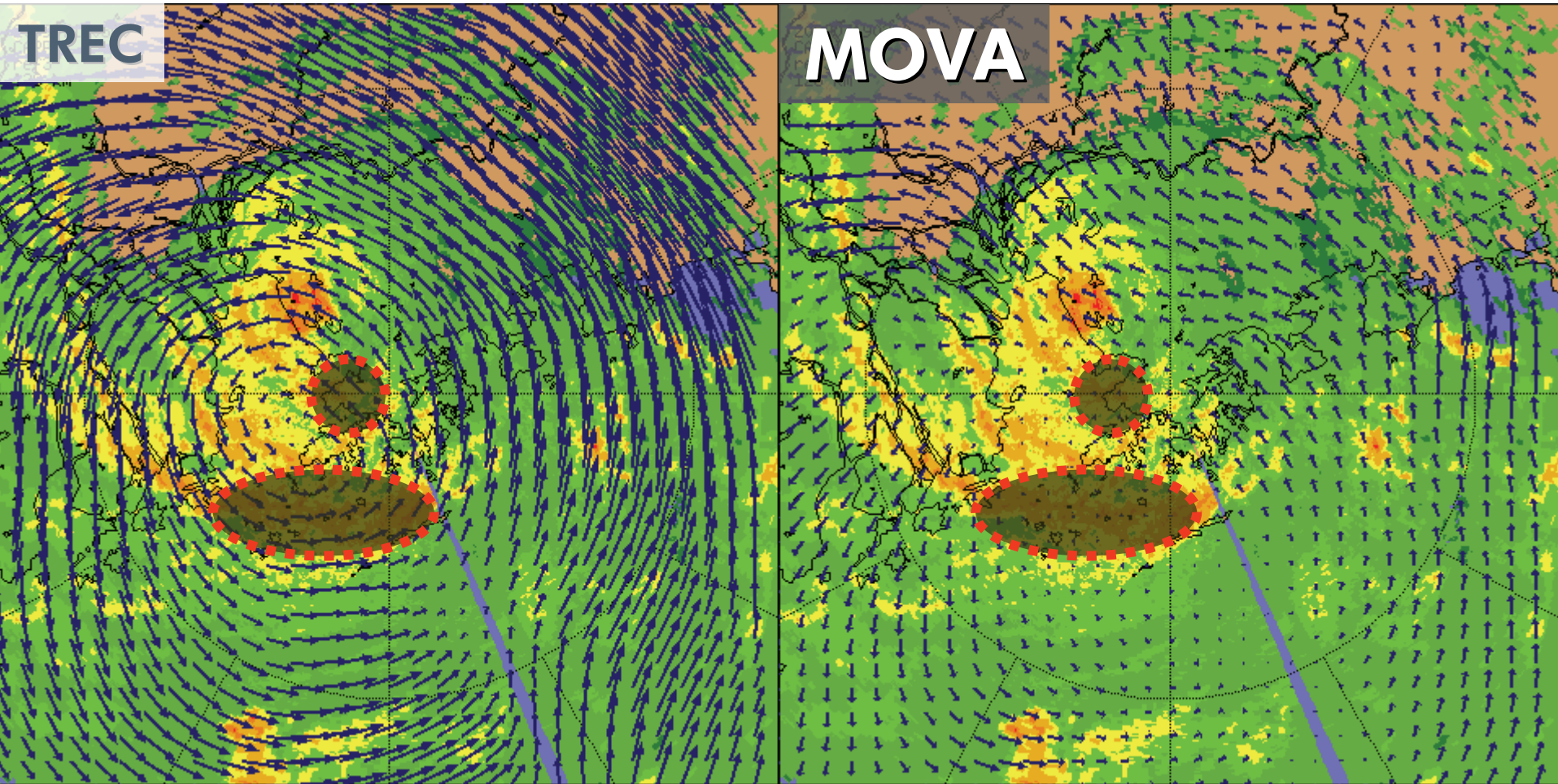
Appendix A

Motion vectors comparion:
MOVA vs TREC vs GTrack

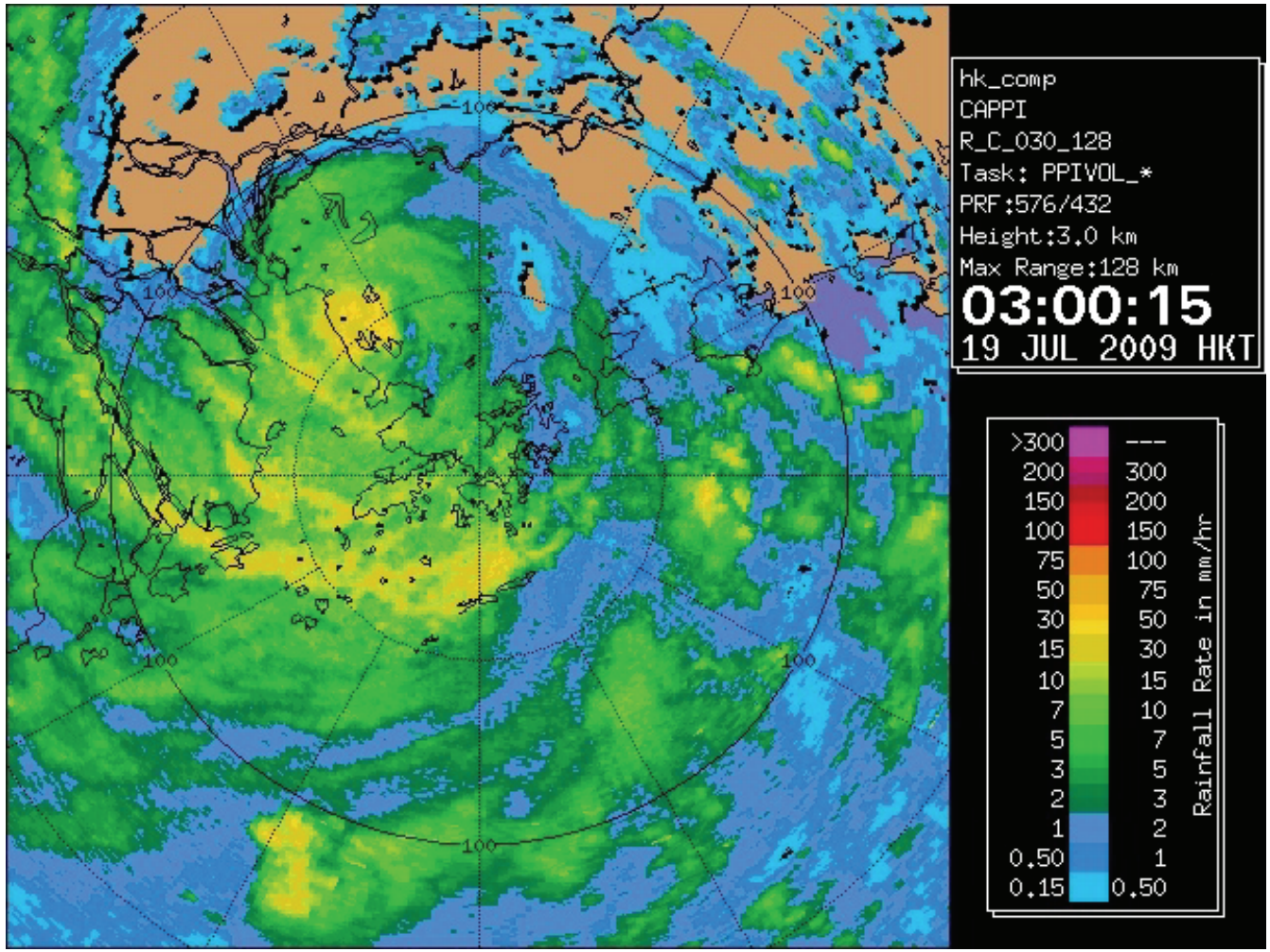
T. Molave – tracking results

2009-07-19 03:00 H



T. Molave – radar sequence

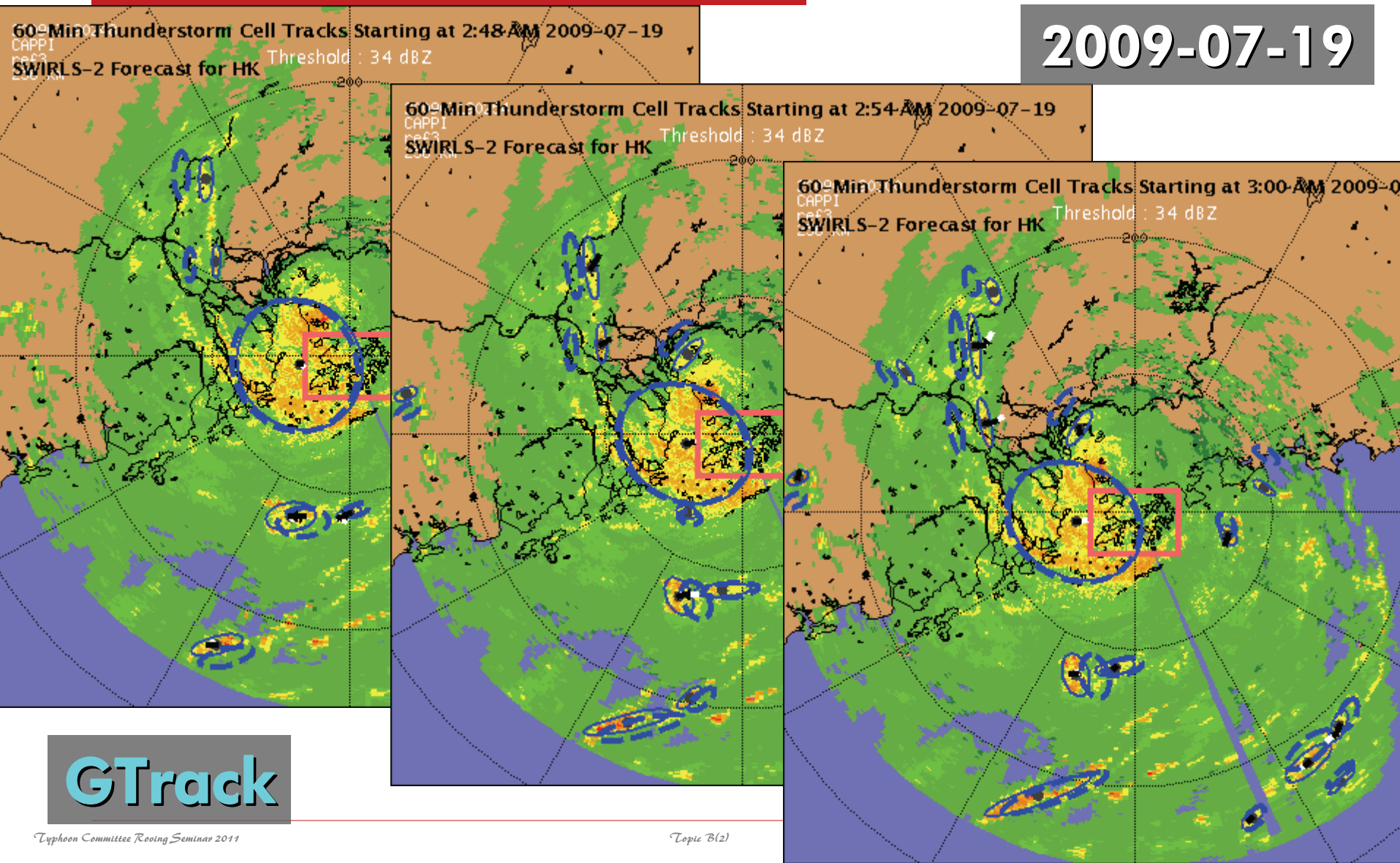
2009-07-19



Radar reflectivity

T. Molave – centroid tracking

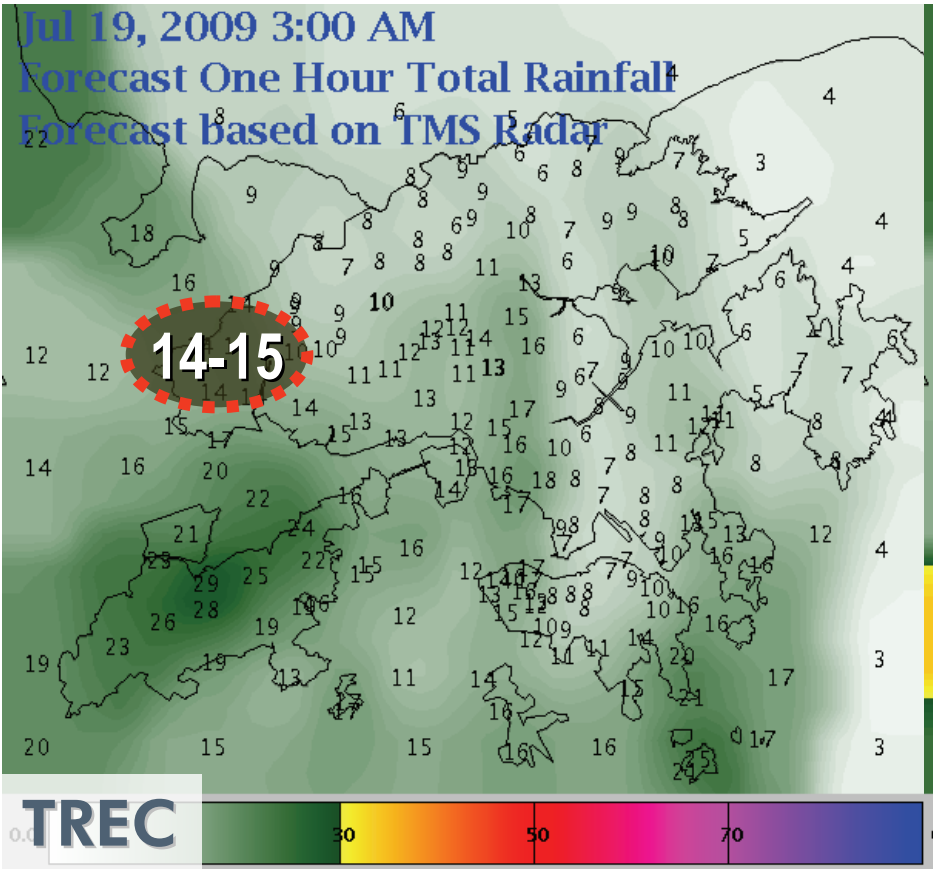
2009-07-19



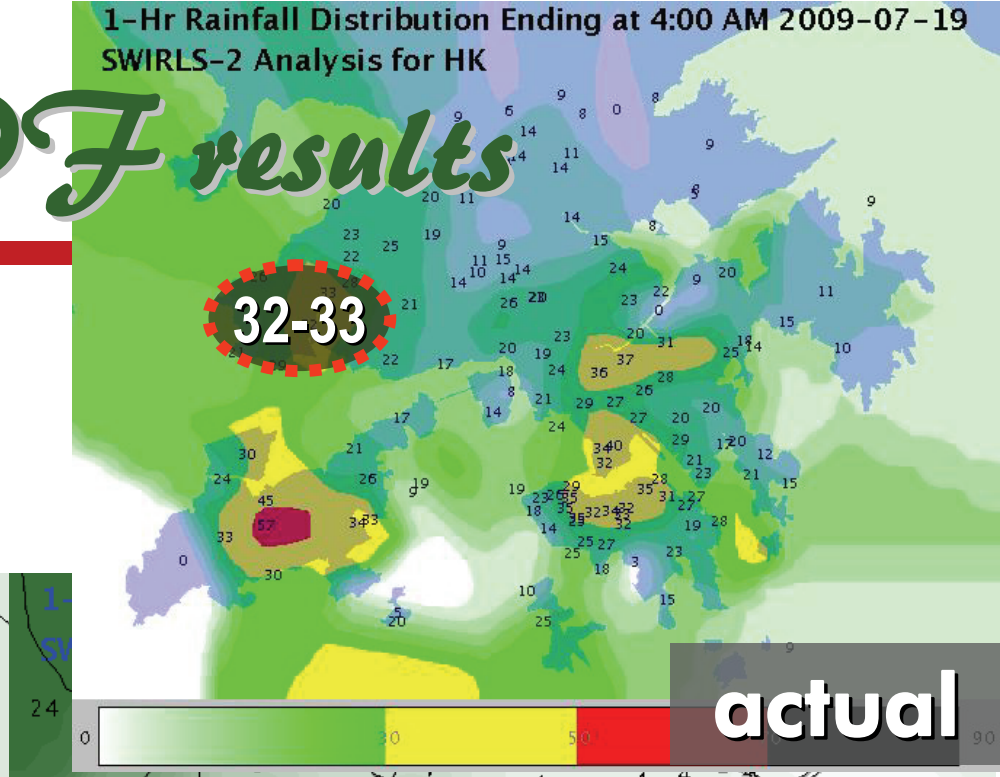
GTrack

T. Molave – QPF results

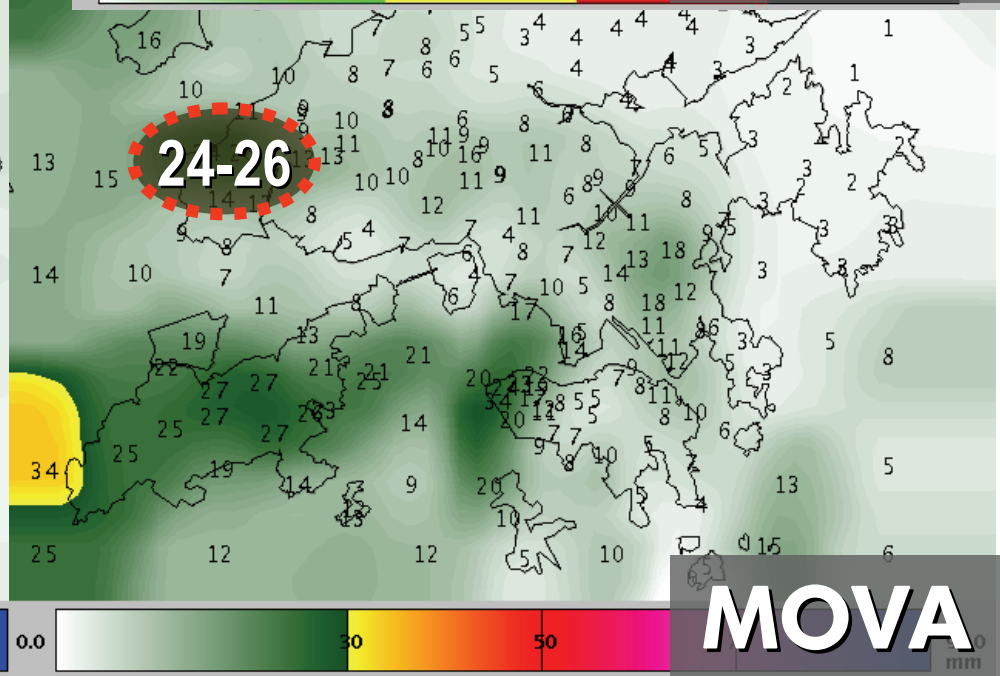
2009-07-19
04:00 H



TREC



actual



MOVA

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Appendix B

Limitations of optical flow technique

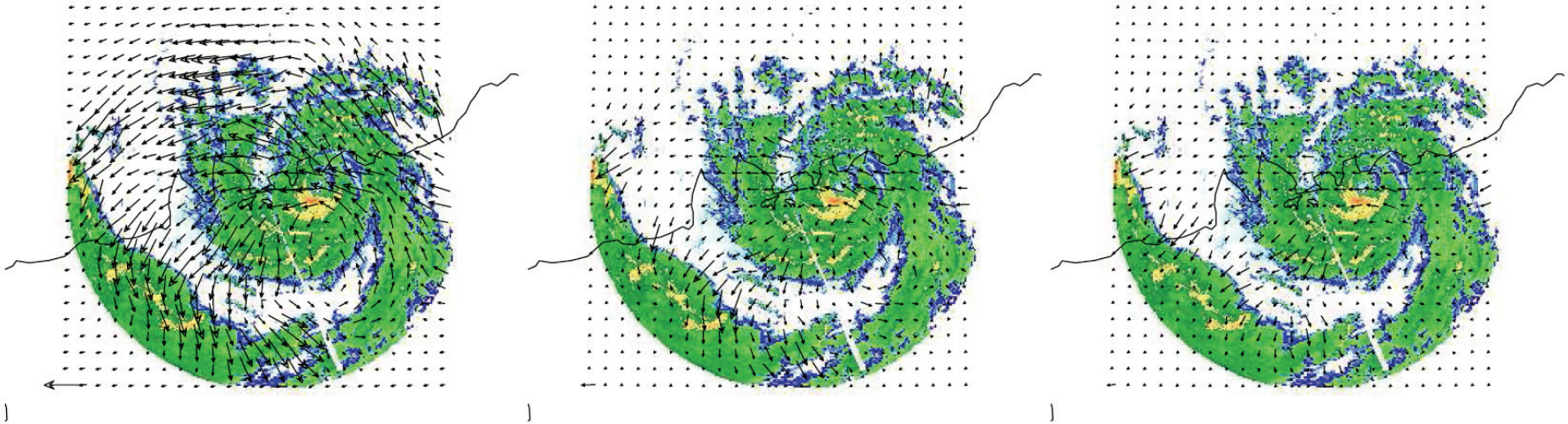
Assumptions of Optical Flow

- no change in intensity
- small displacement
- tracking will tend to be underestimated or even fail if:
  - *motion speed too fast*
  - *tracking time interval too wide*
    - resulting in little or no overlapping of images pattarn
    - cost-function gradient becomes “flat” and minimization algorithm difficult to get to the correct solution

Problematic Tracking Example

6–minute 12–minute 24–minute

MOVA Vector Field km/hour
Reflectivity DBZ

MOVA Vector Field km/hour
Reflectivity DBZ

MOVA Vector Field km/hour
Reflectivity DBZ