

Introduction to Radar Based Nowcasting

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WMO WWRP 4th International Symposium on Nowcasting and Very-short-range Forecast 2016 (WSN16)

What We Need...

Actual

Quantitative Precipitation
Estimate (QPE)

Forecast

Quantitative Precipitation
Forecast (QPF)

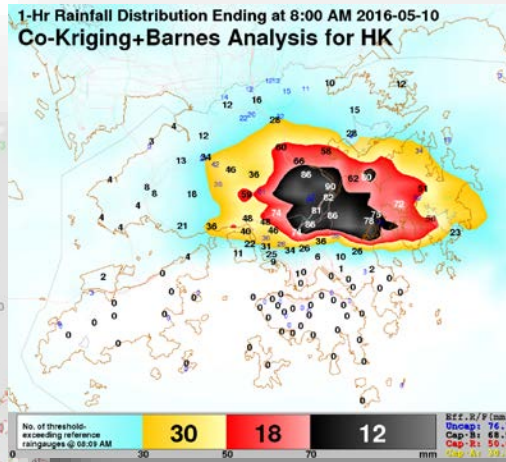
Severe Weather

Lightning, Gust, Hail

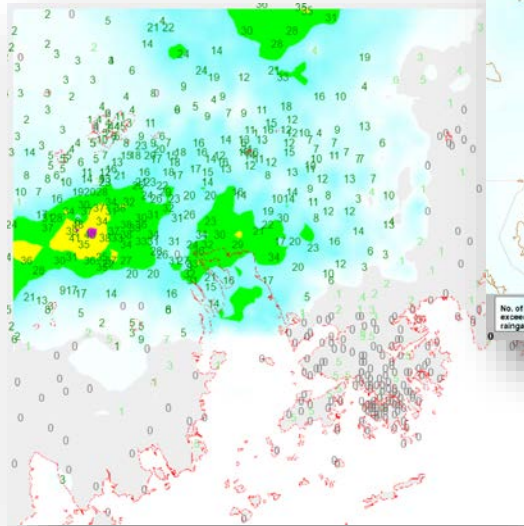
Services

Forecasts & Warnings

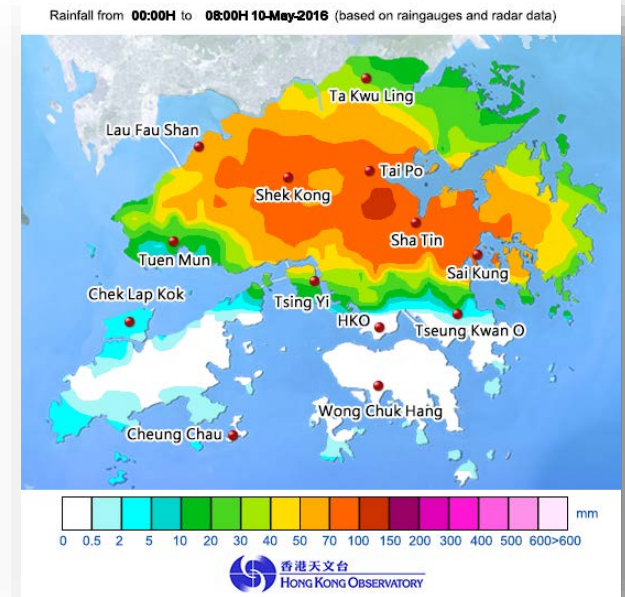
Actual (QPE) Products



Local Rainfall Map
for Forecasters

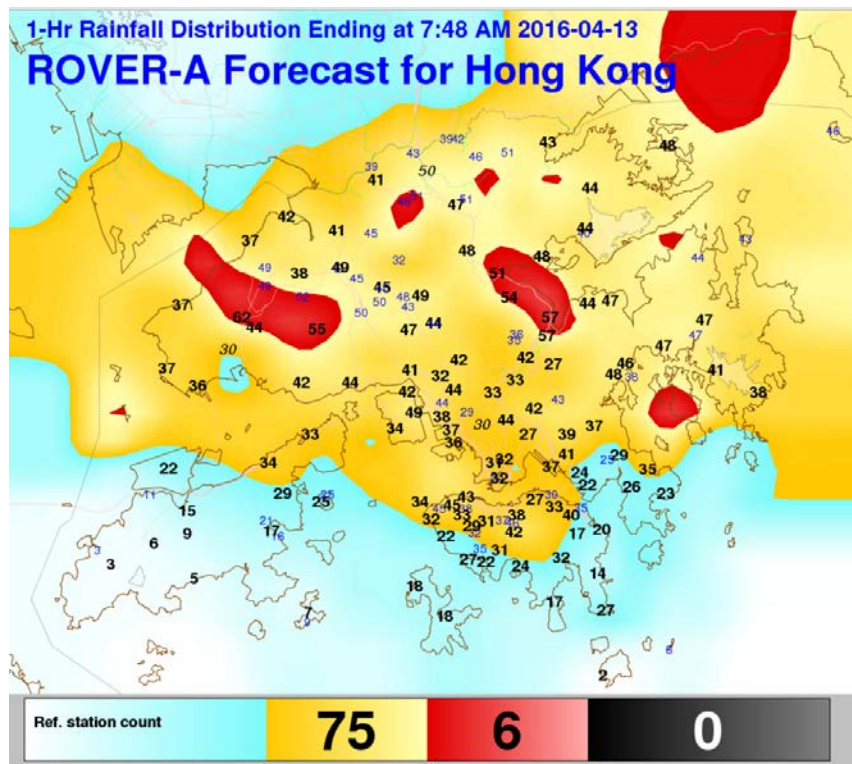


Regional Rainfall Map
on GIS for Forecasters



Local Rainfall Map
for the Public

Forecast (QPF) Products



For Forecasters

我的天文台
定點降雨預報(試驗版)

您所在的位置有雨。

13:18 +½小時 +1小時 +1½小時 +2小時

圖示: 無雨或微雨 (< 0.5毫米) ≥ 0.5毫米

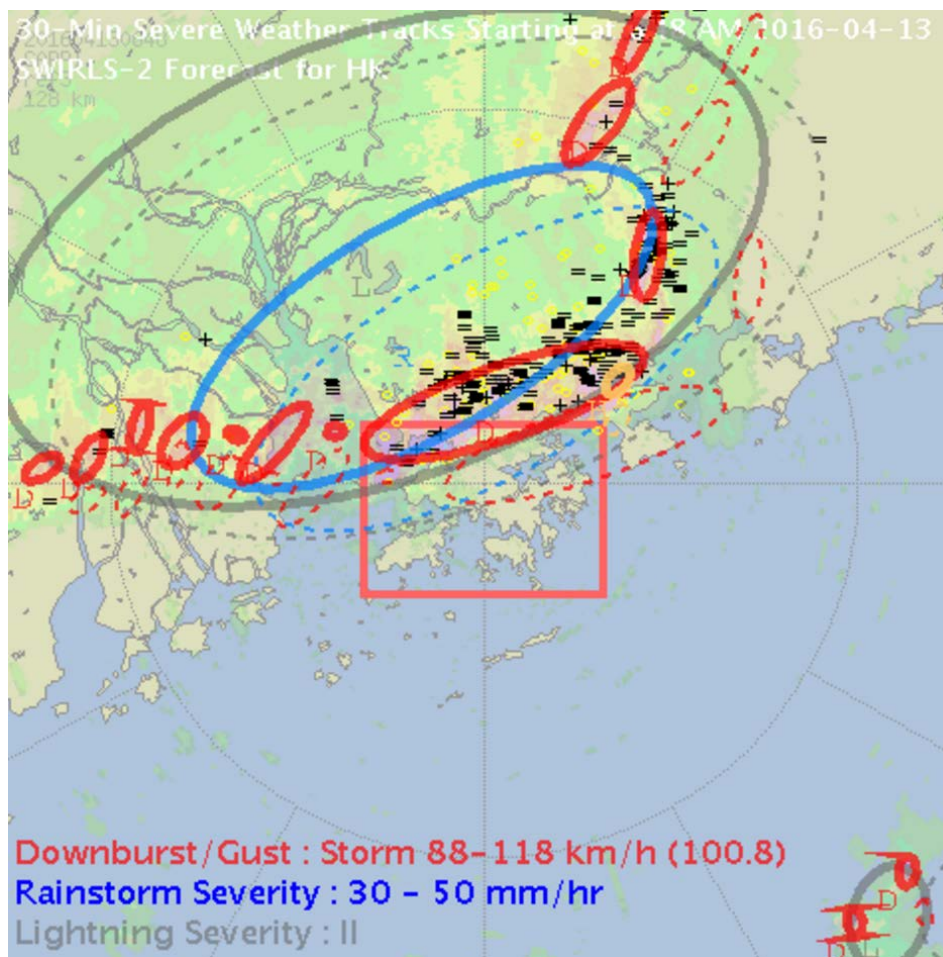
降雨預報動畫

設定
注意事項

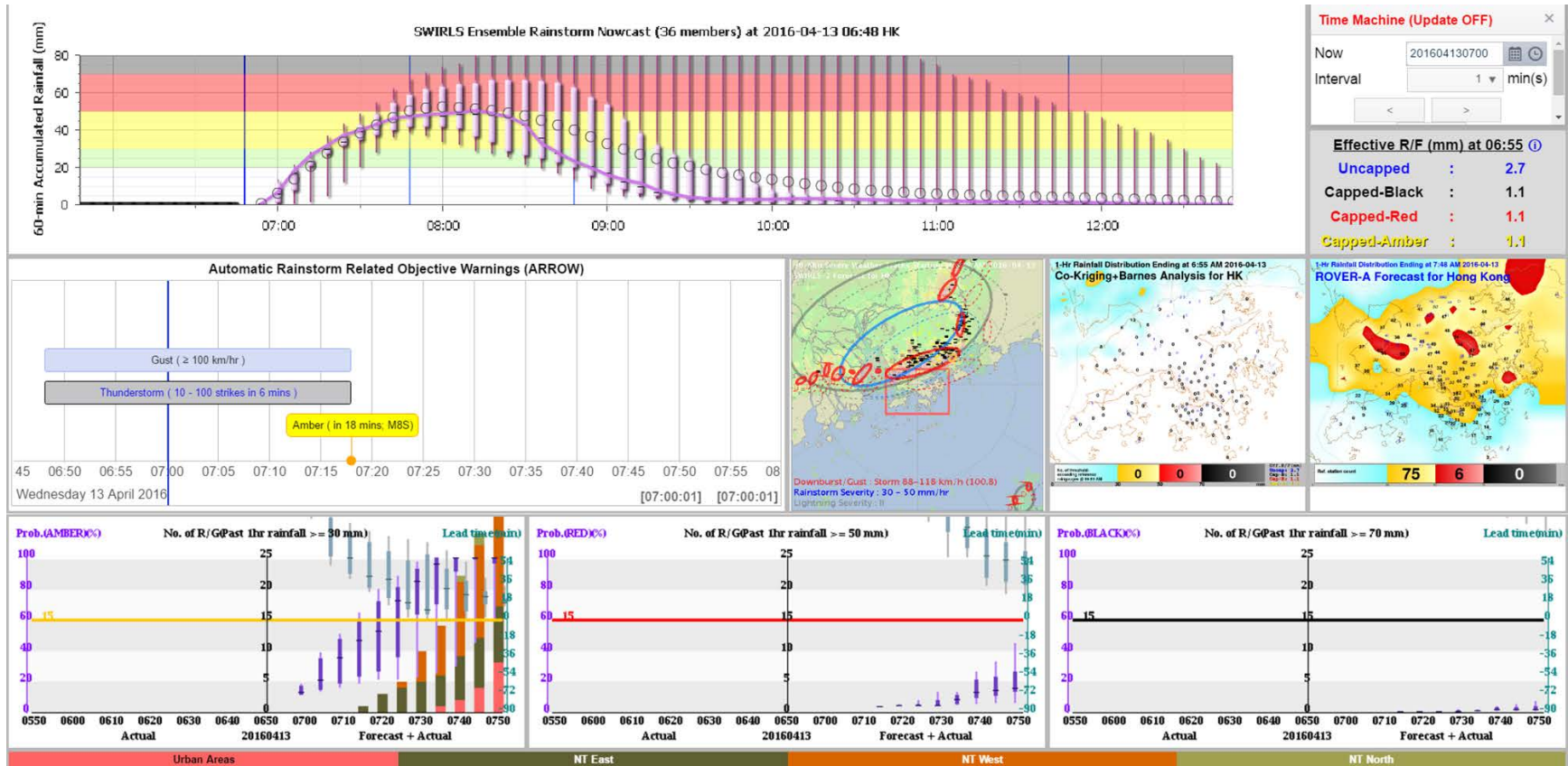
智能電話
Smart Phone

For Public

Severe Weather Products




Services




For Internal Customer (Forecasters)

Services

 **Hong Kong Observatory**
The Government of the Hong Kong Special Administrative Region
Innovate with Science, Serve with Heart

GovHK 香港政府一站通 繁體版 简体版

SEARCH | SITE MAP | 

Home
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Weather Information for Communities
China Weather
World Weather
Climatological Information Services
Climate Forecast
Climate Change
El Nino and La Nina
Earthquakes and Tsunamis
Astronomy, Space Weather and Geomagnetism
Time and Calendar

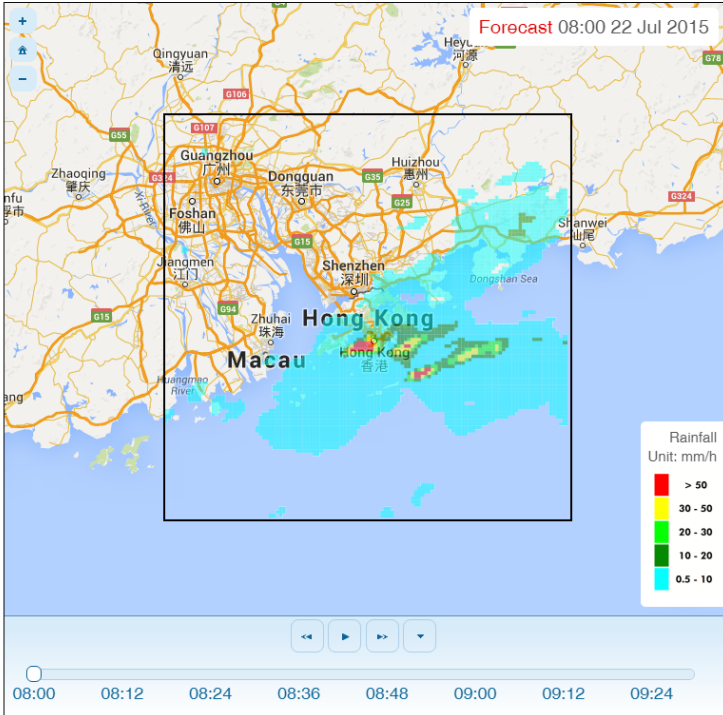
Two-hour Rainfall Nowcast for Hong Kong and Pearl River Delta

[Fixed-area map version](#)

Objective Forecast Product
* Generated automatically by computers, without any manual adjustment.*
** Refer to the official weather bulletins of Guangdong, Hong Kong and Macau for detailed forecasts and warnings, available at [Greater Pearl River Delta Weather Website](#) **

To enhance user experience, this web page was updated on 8th September 2015, adopting a geographical information platform that does not require installation of software.

Forecast 08:00 22 Jul 2015



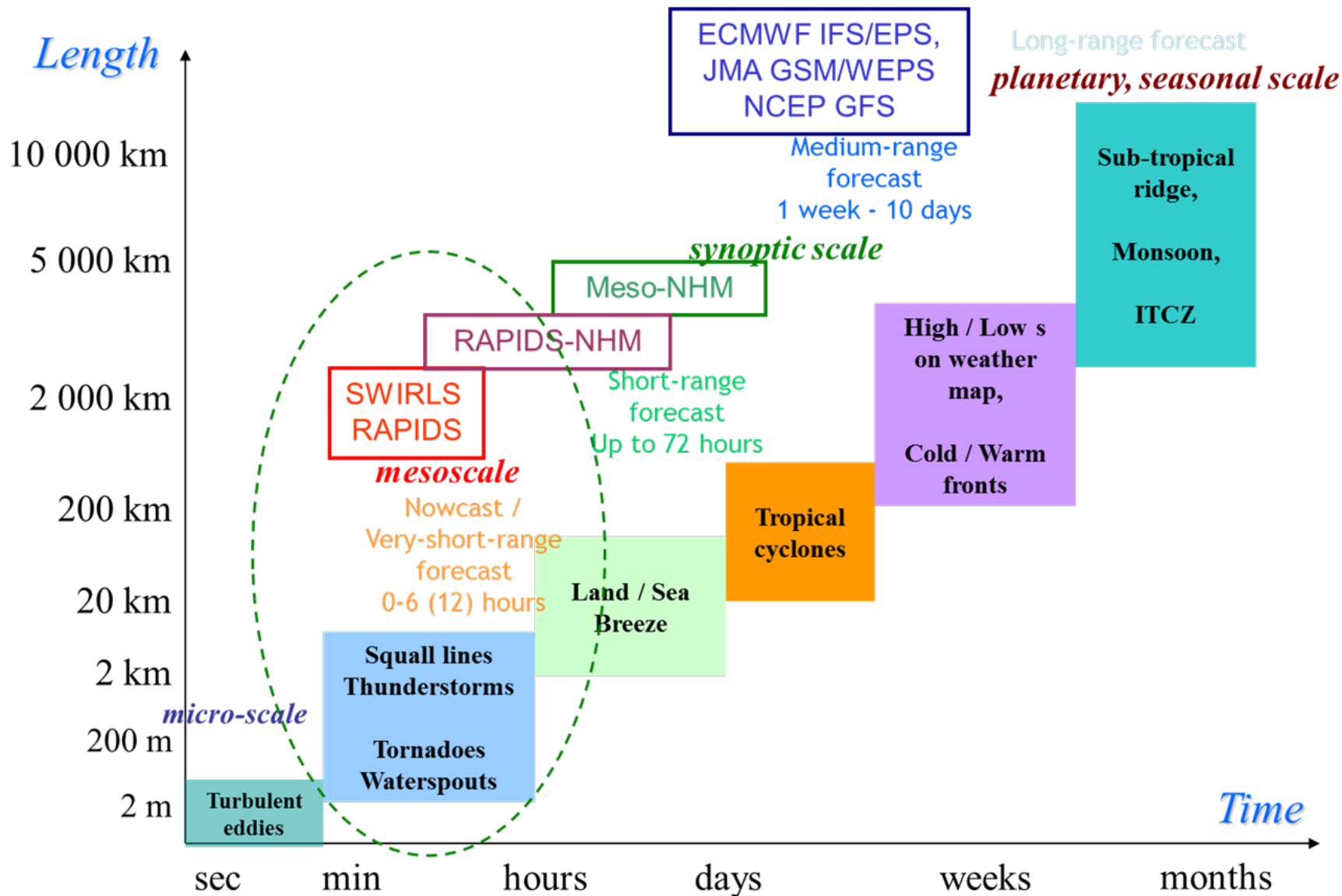
Rainfall Unit: mm/h

- > 50
- 30 - 50
- 20 - 30
- 10 - 20
- 0.5 - 10

08:00 08:12 08:24 08:36 08:48 09:00 09:12 09:24

For Public

Scale matters ...



WEATHER WARNINGS

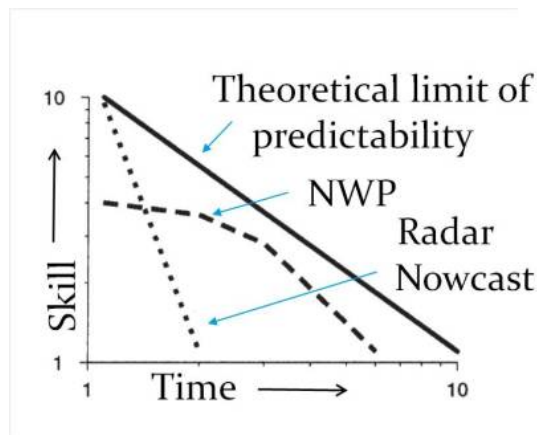
Radar-based vs NWP-based

Radar-based

- Basically Image Processing
 - Correlation-based
 - Optical flow
 - Convolutional LSTM
- Good for first few hours
- Skills deteriorates rapidly afterwards

NWP-based

- Based on *Primitive Equations*
- Not so good for first few hours due to spin-up problem
- More skillful than Radar-based afterwards



Rain Gauge vs Radar vs Satellite



Rain Gauge



Radar



Satellite

Type	In-situ	Remote Sensing	Remote Sensing
Accuracy	Best	Moderate	Worst
Spatial Resolution	Discrete	Continuous, up to 200 m	Continuous, up to 500 m
Spatial Coverage	At point only	Regional, effective up to 256 km (radius)	Half the Globe (geostationery)
Cost	Cheap as single unit Expensive as network	Expensive to operate	Expensive to launch Cheap to use

SWIRLS – HKO Rainstorm Nowcasting System

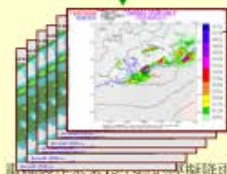
電腦模擬大氣物理過程 Computer Simulation of Physical Processes in the Atmosphere



遙感及常規天氣觀測資料
Remote-sensing and conventional weather observation data



高分辨率風暴模式，直接模擬未來15小時雨雲的演變過程
High-resolution storm model to directly simulate the evolution of precipitating clouds up to 15 hours ahead

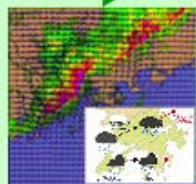


電腦生成之未來1至6小時降雨預測圖
Computer-generated forecast rainfall maps for the next 15 hours based on simulation

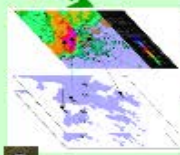
雷達追蹤、分析及預測 Radar Tracking, Analysis and Forecast



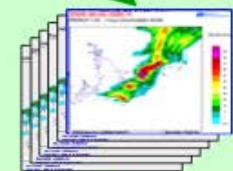
「小渦旋」
臨近預報系統
SWIRLS
Nowcasting
System



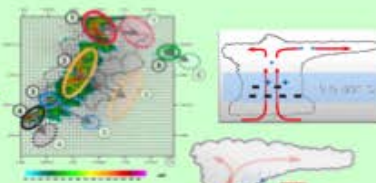
利用雷達自動追蹤及估計雨帶的移動路徑
Automatic tracking and prediction of rainband movement from radar



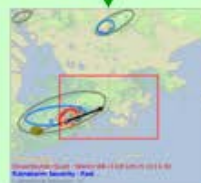
利用密集雨量站數據，實時訂正雷達探測降雨率
Real-time calibration of radar-detected rainfall rate using the dense raingauge network



電腦製作未來1至6小時的雷達降雨預測圖
Computer-generated forecast rainfall maps up to 6 hours ahead based on radar



強風暴單體識別及雷達特徵分析
Cell identification and radar signature analysis for severe storms

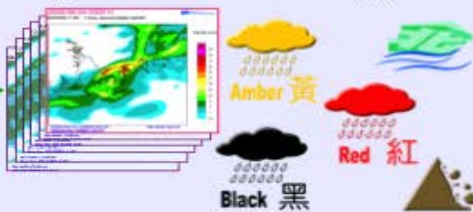


電腦製作狂風、閃電、冰雹及大雨預測圖
Computer-generated forecast map of squalls, lightning, hail and heavy rain

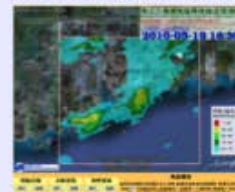
支援暴雨及相關警告系統 In support of Rainstorm and Related Warning Systems



融合雷達臨近預報及電腦模擬結果的未來1至6小時雨量預測圖
Forecast rainfall maps up to 6 hours ahead blended from radar nowcast and computer simulation results



「珠三角」降雨臨近預測圖在天文台網站公開發放 Public dissemination of nowcast rainfall maps for the Pearl River Delta region via HKO Internet website



降雨預測資料透過四維立體地圖顯示
Forecast rainfall information visualized with 4-dimensional map of the globe

臨近預報產品及服務 Nowcast Products & Services

支援國際盛事 In support of Important International Events



支援雷暴警告系統 In support of Thunderstorm Warning System



SWIRLS –

Short-range Warning of Intense Rainstorm in Localized Systems

- ACTUAL :- Quantitative precipitation estimation (QPE)
 - radar-based, raingauge-based and blending with satellite cloud images
- TREND :- Retrieval of echo motion
 - tracking by maximum correlation (TREC)
 - tracking by optical flow
 - object-oriented tracking of storm motion
- FORECAST :- semi-Lagrangian advection to extrapolate radar reflectivity up to 6 / 9 hours
- OUTPUTS :- computation of gridded precipitation nowcast (QPF) and locations of storm objects on convective wind gust, lightning and hail, support to decision making
- UNCERTAINTY :- probabilistic QPF and blending with convection-permitting NWP model
- PRODUCTS :- nowcasting products for internal users and public

QPE – Rainfall Calibration Module

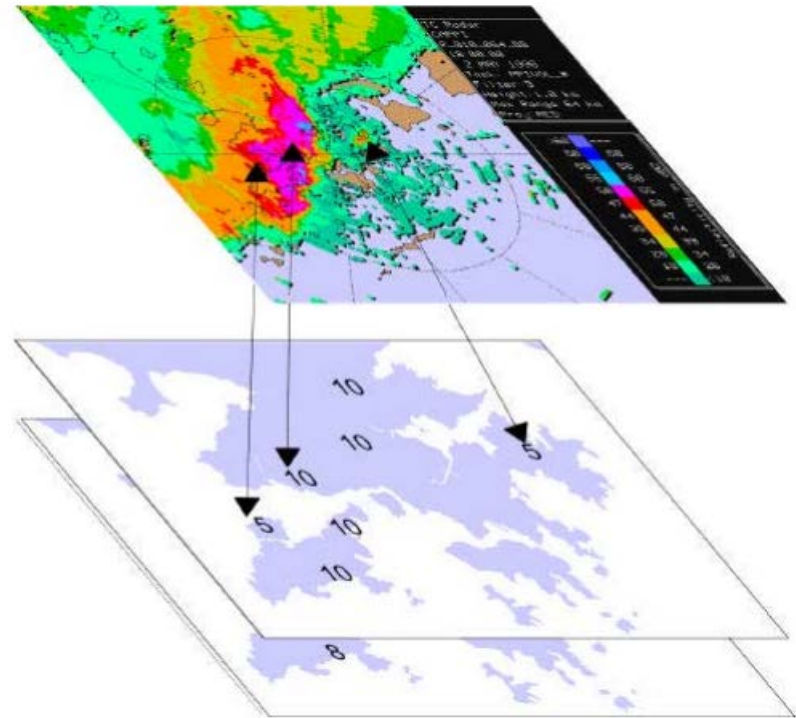
- Schematic diagram showing the calibration of radar reflectivity using real-time raingauge measurement.

- Z-R relation for converting reflectivity to rainfall rate

$$Z = aR^b$$

$$dBZ_i = b \text{ dBG}_i + 10\log(a)$$

- Gridded rainfall analysis computed by Barnes successive correction or more advanced co-kriging algorithm



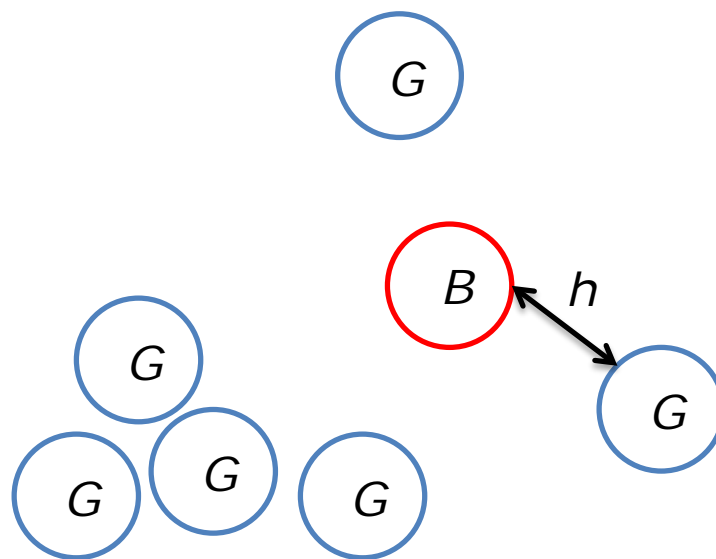
Barnes Analysis

- grid-point analysis by Barnes method
 - interpolation with Gaussian weighting according to distance between data & estimation point
 - consider correction using residuals and grouping of rain gauges

$$B(x_0) = \frac{\sum_{i=1}^{N_0} w_i G_i}{\sum_{i=1}^{N_0} w_i}$$

$$w_i = \exp\left(\frac{-h_i^2}{L^2}\right)$$

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



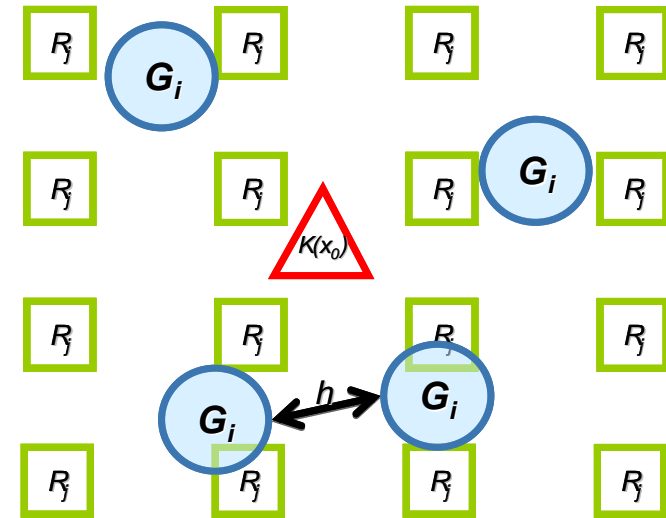
Co-kriging Analysis

Symbol	Meaning	Unit
$K(x_0)$	rainfall estimated by Kriging/Co-Kriging at location x_0	mm
$\sigma^2(x_0)$	the corresponding estimation variance at location x_0	mm ²
N_0	number of rain gauges in the neighbourhood of x_0	-
M_0	number of radar grid points in the neighbourhood of x_0	-
G_i	data reported at the i -th rain gauge located at $x_i, i = 1, \dots, N_0$	mm
R_j	data observed at the j -th radar grid point located at $x_j, j = 1, \dots, M_0$	mm
$\lambda_i(x_0)$	weight of the i -th rain gauge data w.r.t. x_0	-
$\lambda_j(x_0)$	weight of the j -th radar data w.r.t. x_0	-
$\Gamma_{GG}(x_a, x_b)$	semivariogram of rain gauge data between any two locations x_a and x_b	mm ²
$\Gamma_{RR}(x_a, x_b)$	semivariogram of radar data between any two locations x_a and x_b	mm ²
$\Gamma_{GR}(x_a, x_b)$	cross-semivariogram of rain gauge data at x_a and radar data at x_b	mm ²
$\mu_{G,R}(x_0)$	are the two Lagrange multipliers accounting for the two unbiasedness constraints on the gauge or radar weights w.r.t. location x_0	mm ²

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

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



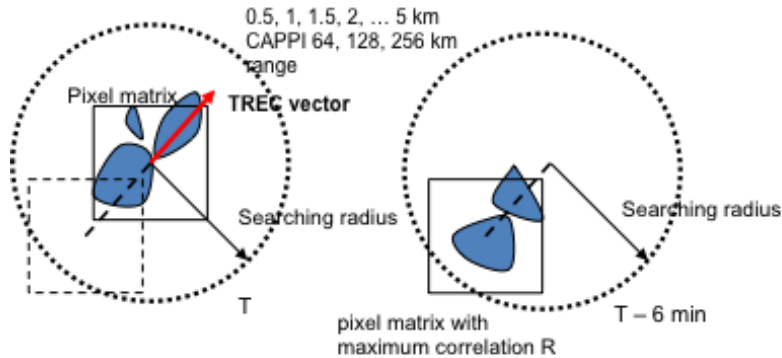
Solution:

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

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

Radar echo tracking in SWIRLS

Maximum Correlation (TREC)



where Z_1 and Z_2 are the reflectivity at $T+0$ and $T+6\text{min}$ respectively

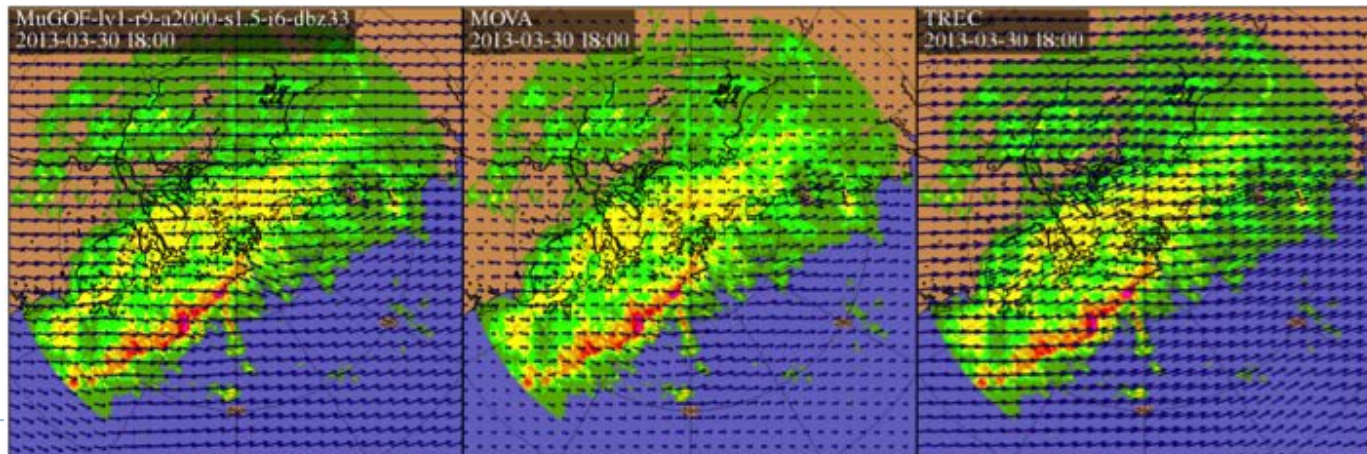
$$R = \frac{\sum_k Z_1(k) \times Z_2(k) - \frac{1}{N} \sum_k Z_1(k) \sum_k Z_2(k)}{\left[\left(\sum_k Z_1^2(k) - N \bar{Z}_1^2 \right) \times \left(\sum_k Z_2^2(k) - N \bar{Z}_2^2 \right) \right]^{1/2}}$$

Optical Flow

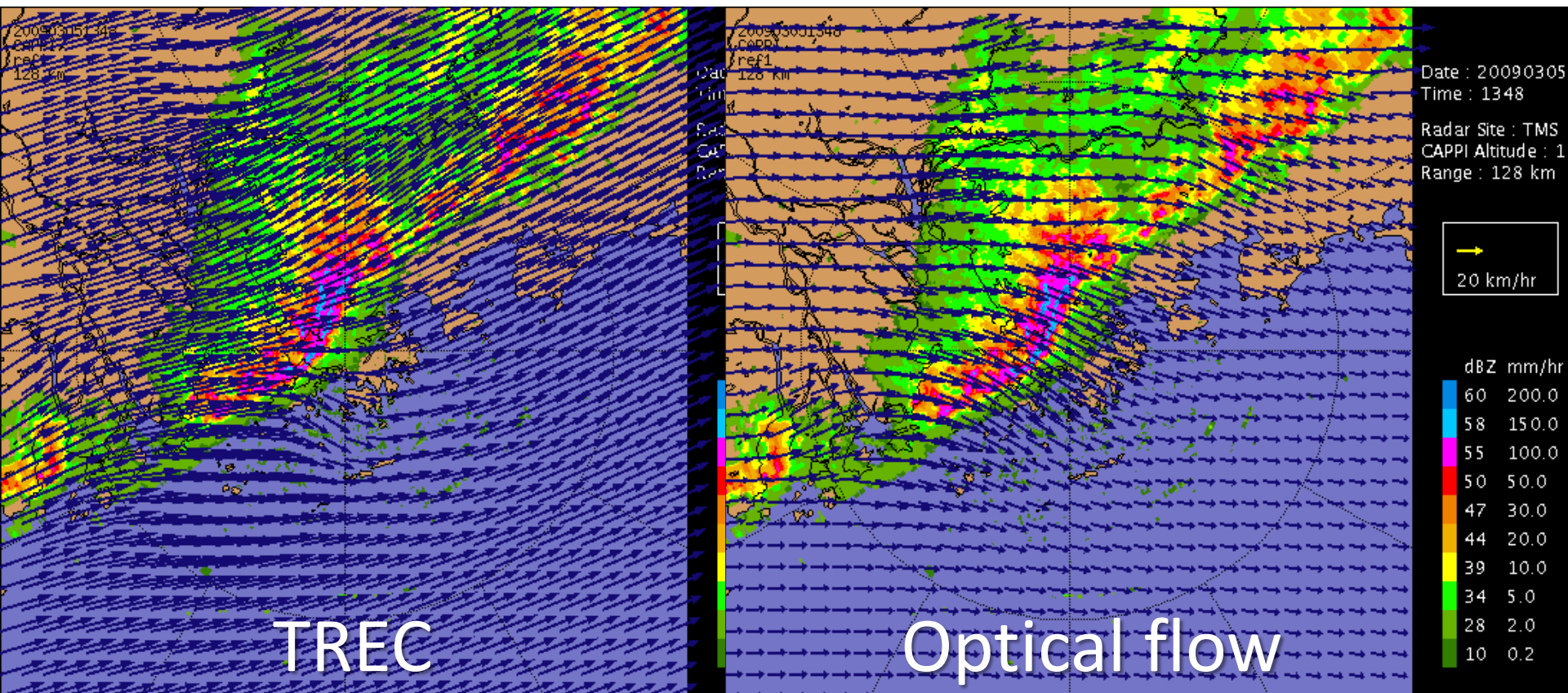
Given $I(x,y,t)$ the image brightness at point (x,y) at time t and the brightness is constant when pattern moves, the echo motion components $u(x,y)$ and $v(x,y)$ can be retrieved via minimization of the cost function:

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

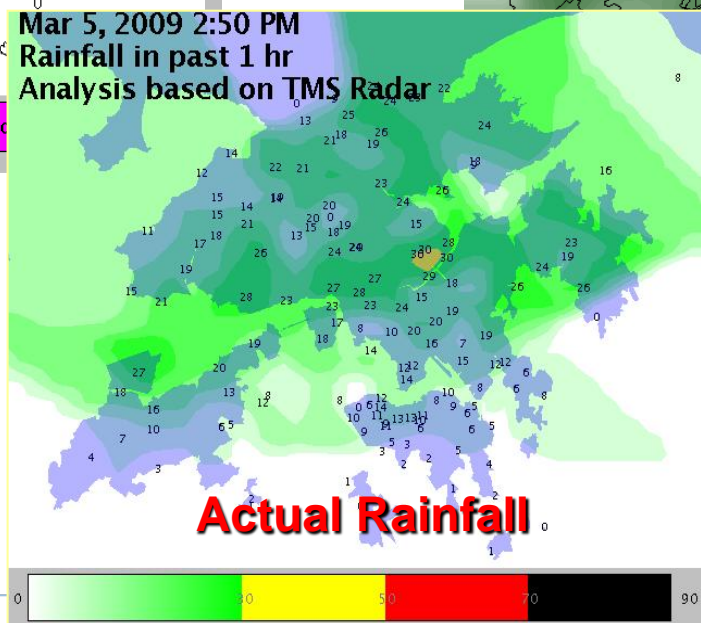
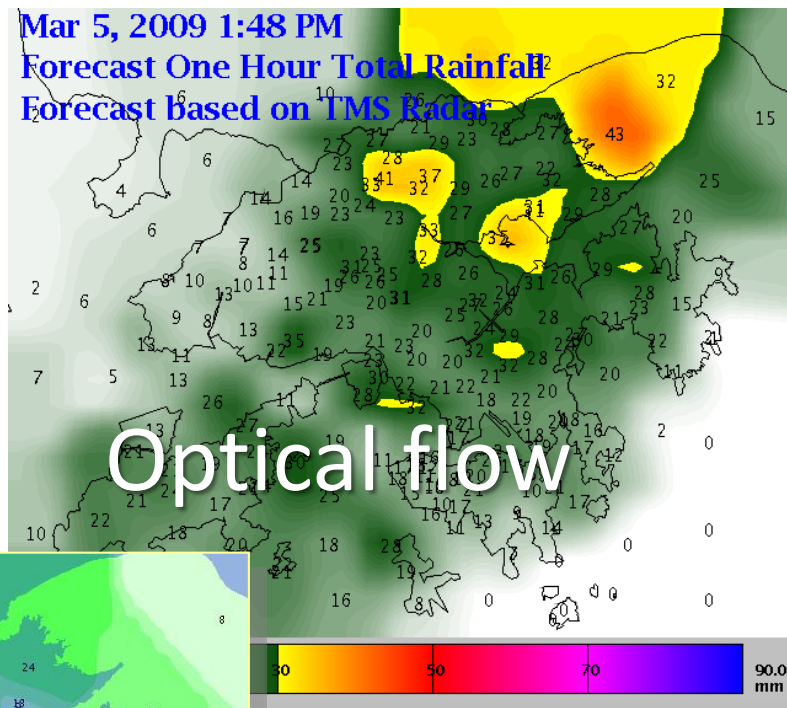
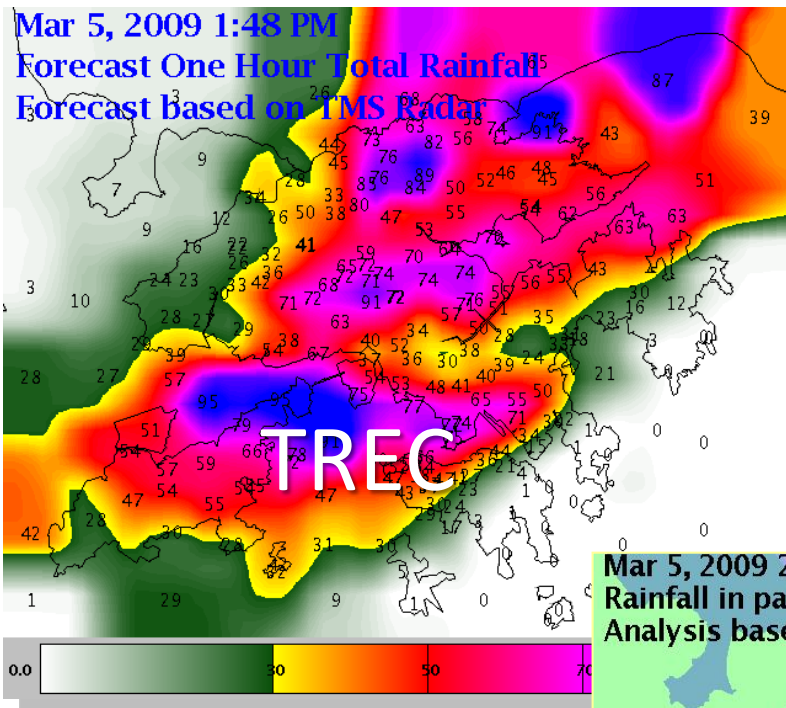
$$\nabla J = 0 \Rightarrow (u, v)$$



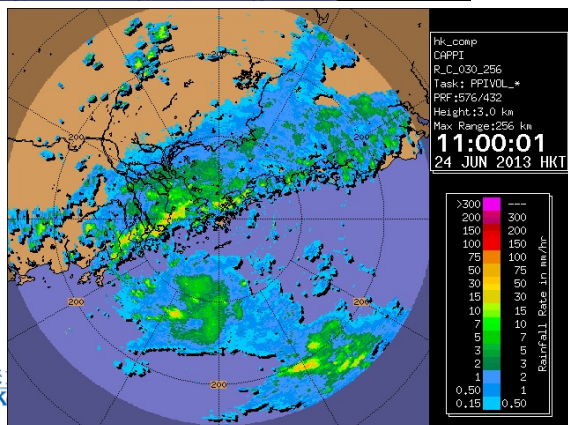
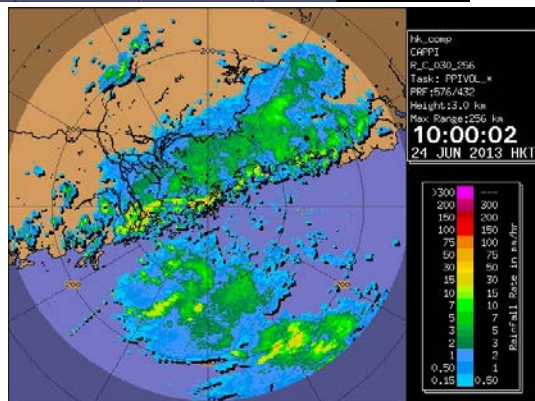
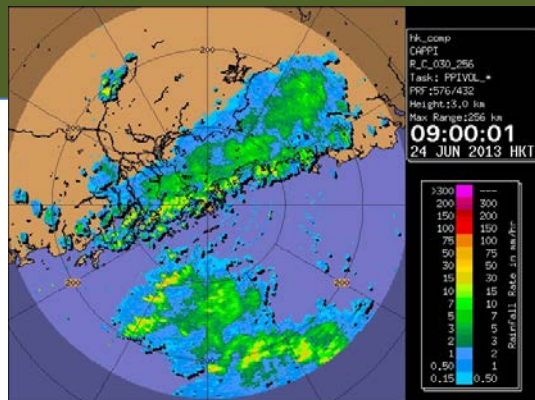
Comparison of echo tracking



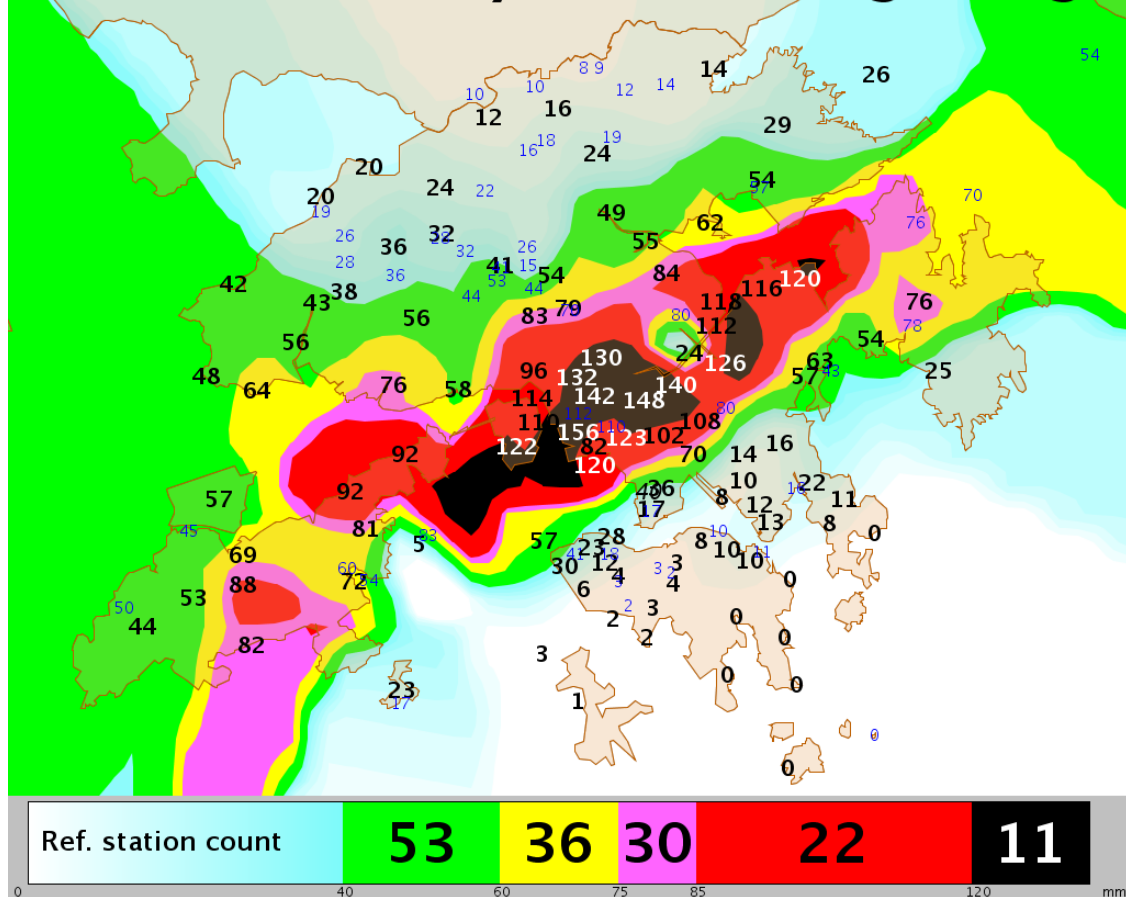
1-hr Quantitative Precipitation Forecast (QPF)



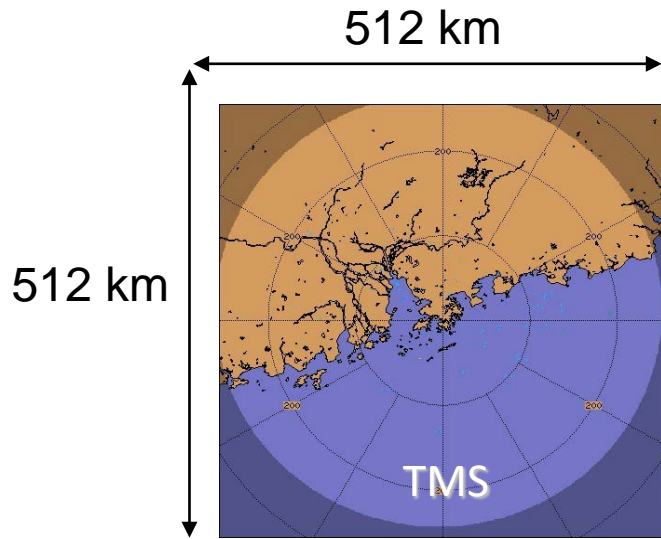
Rainfall nowcast from SWIRLS



3-Hr Rainfall Distribution Ending at 10:55 AM 2013-06-24 SWIRLS-2 Analysis for Hong Kong



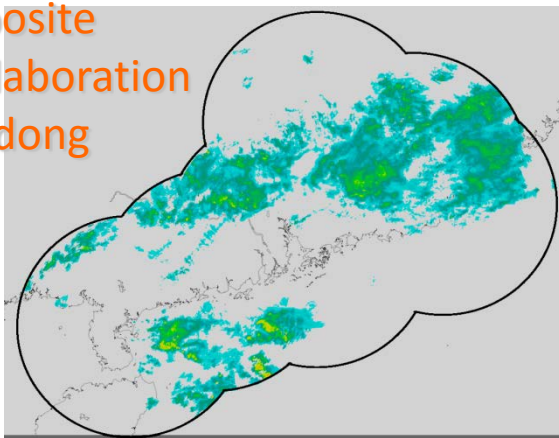
Multi-Sensor QPE/QPF



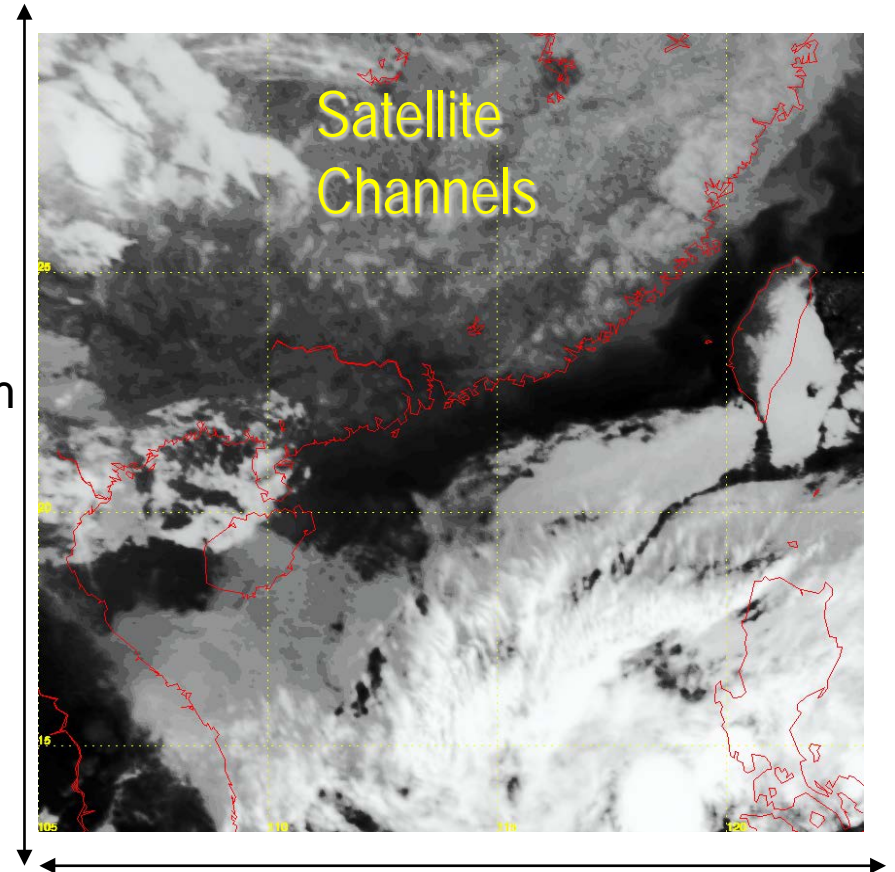
1728 km

Radar composite
through collaboration
with Guangdong

904 km



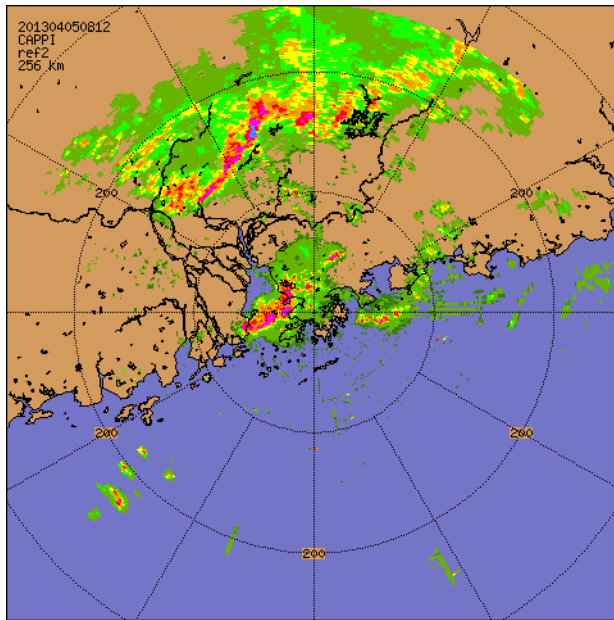
1158 km



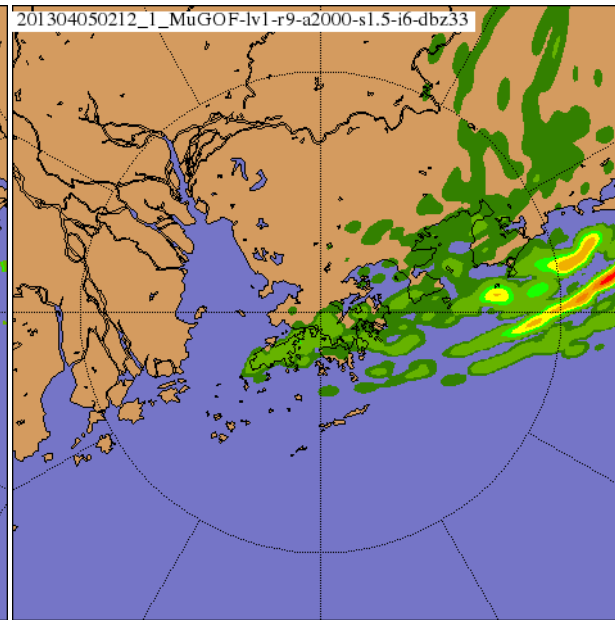
1804 km

9-hour Nowcast of Radar Reflectivity

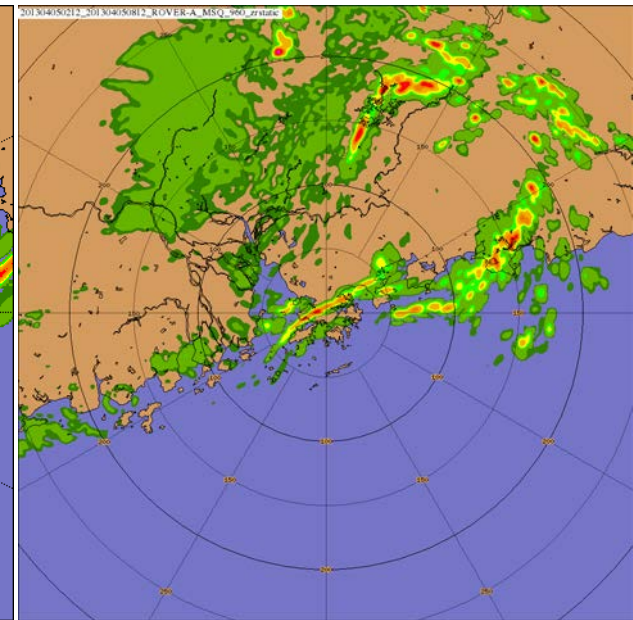
Base Time : 2013-04-05 02:12 HKT (6 hour forecast)



Actual



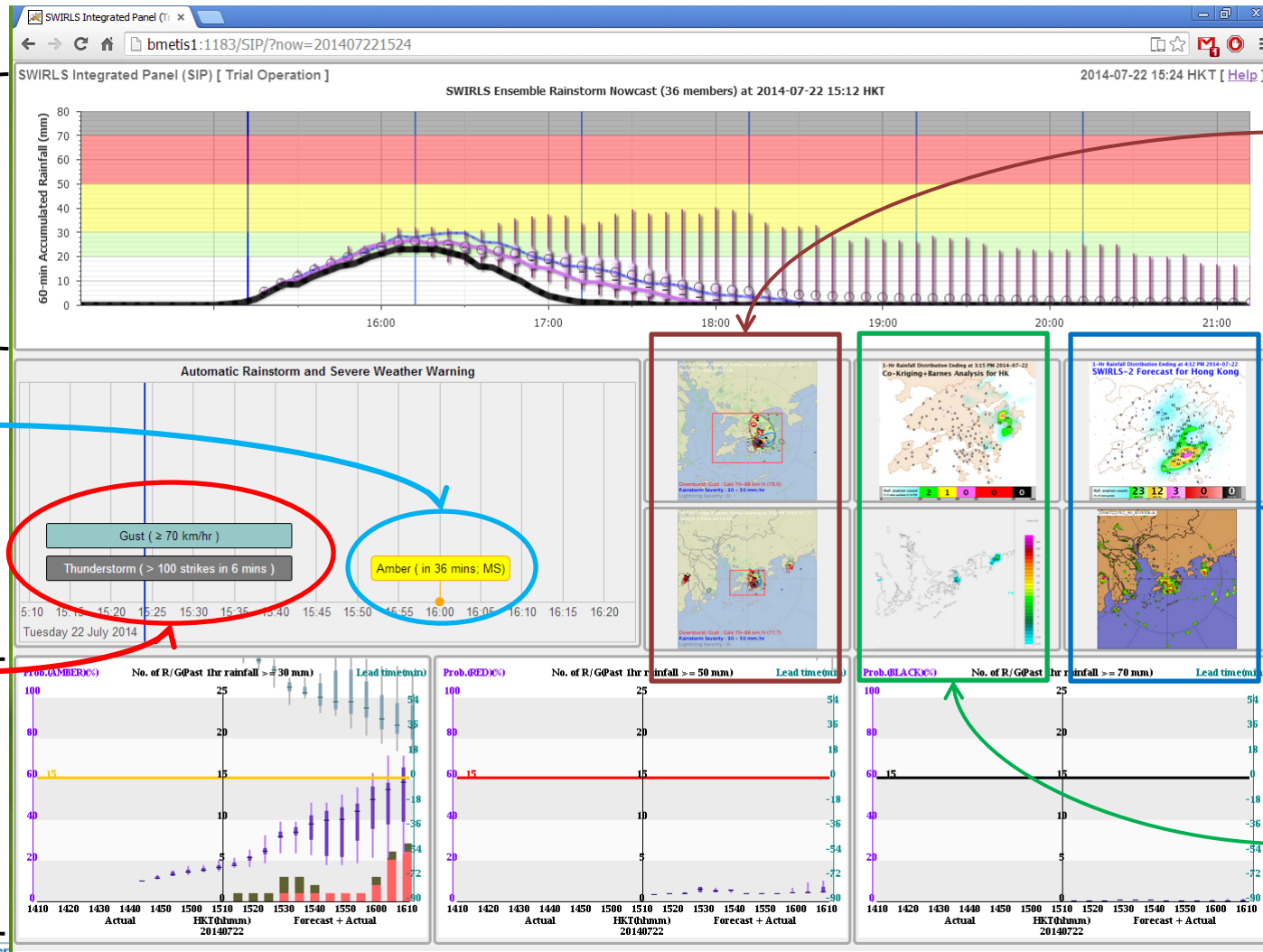
Extrapolate with only
Hong Kong Radars



Extrapolate with Multi-
Sensors

Decision Support - SWIRLS Integrated Panel

Sample Time : 2014-07-22 15:24



SWIRLS Severe Weather Viewer

Forecast Rainfall (QPF)

Actual Rainfall (QPE)

SWIRLS Ensemble Rainstorm Nowcast (SERN)

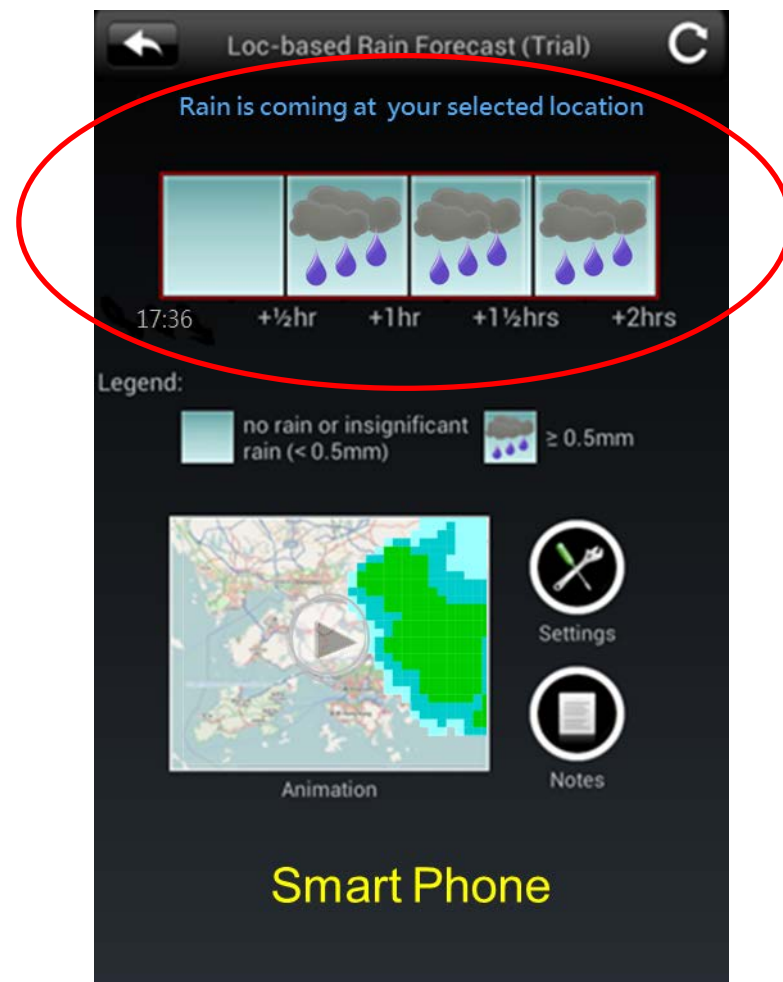
Amber expected in 36 minutes with criteria M and S met

Thunderstorm with high gusts expected during this period

SWIRLS Rainstorm Viewer

Location-based Nowcasting Service

- Available on “MyObservatory” mobile app
- rainfall nowcast for the next 2 hours at your location
 - data from SWIRLS QPF
- personalized automatic alerting service based on user location and expected rainfall

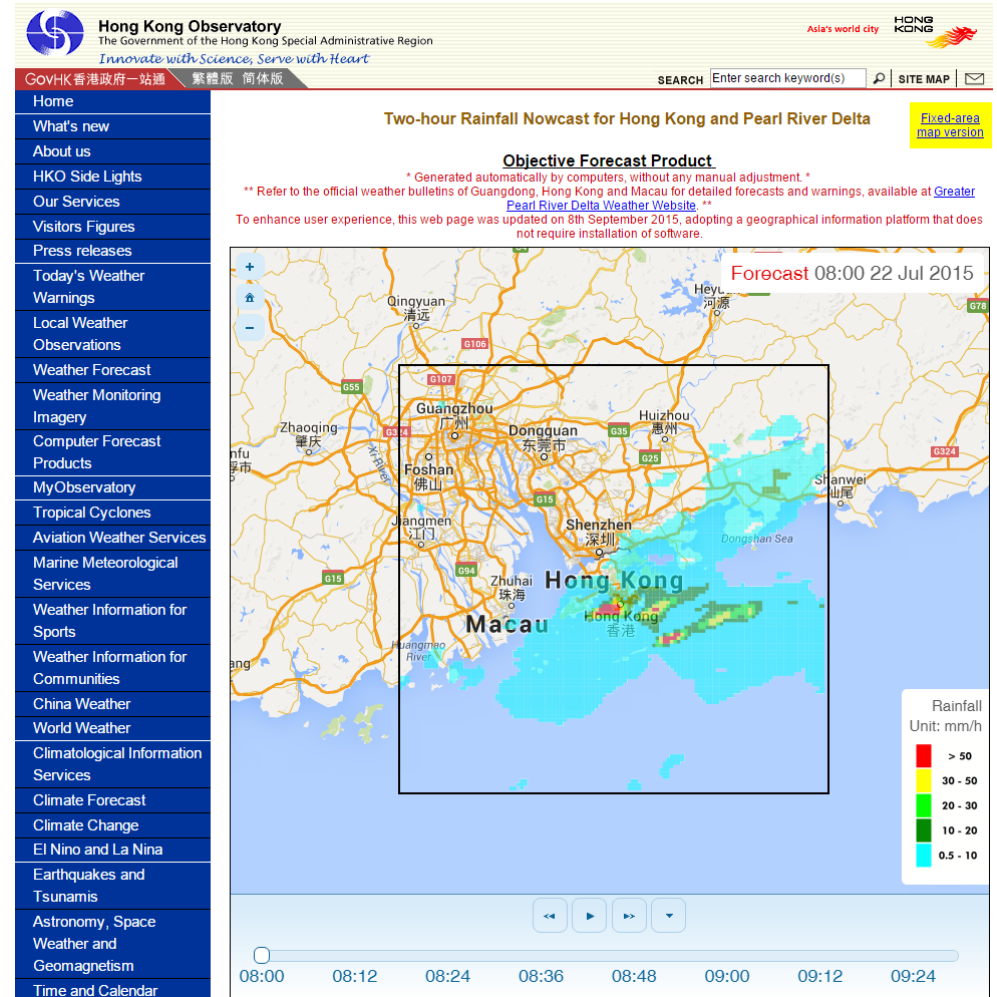


Location-specific Nowcasting Service

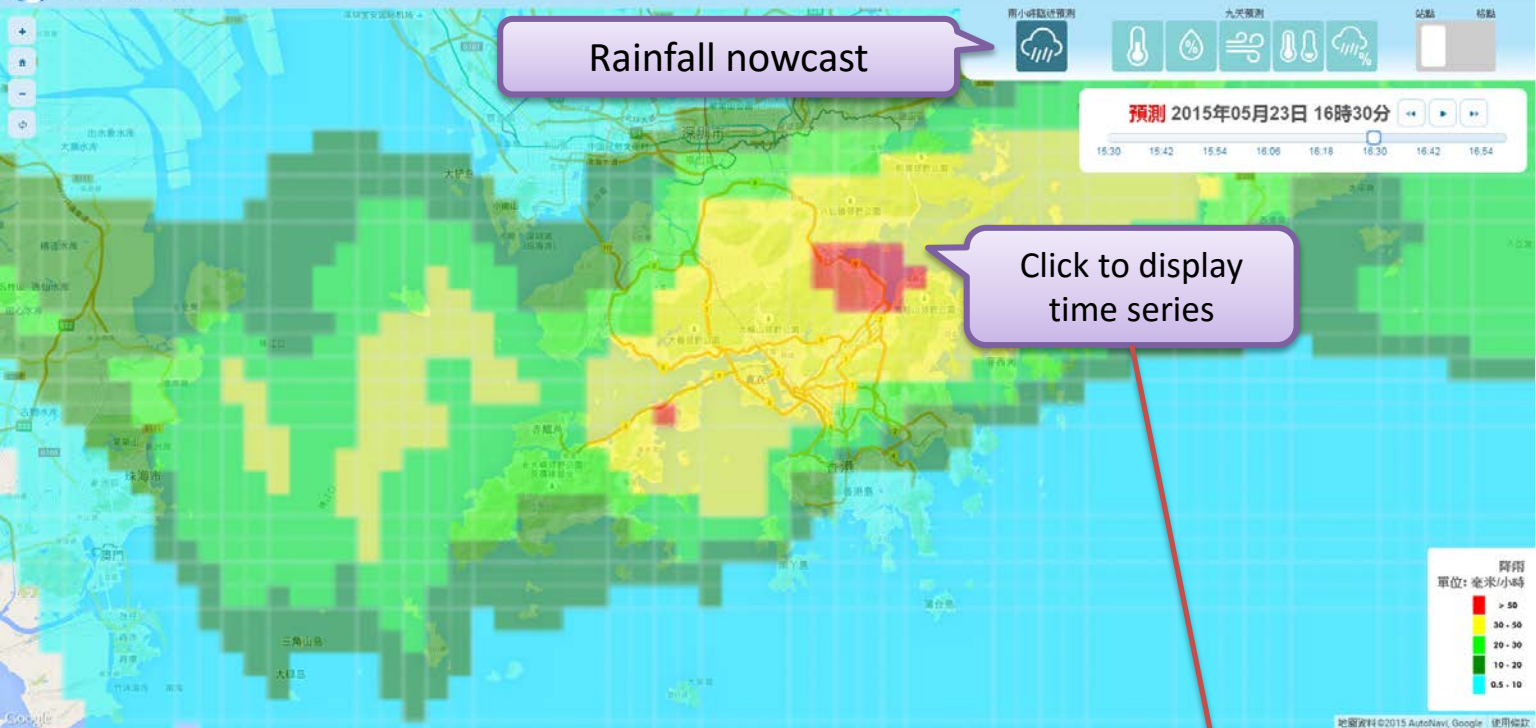
- Personalized & customizable:
 - update frequency
 - notification intervals
 - range of detection
 - forecast location
 - as set on a map

Integration with GIS

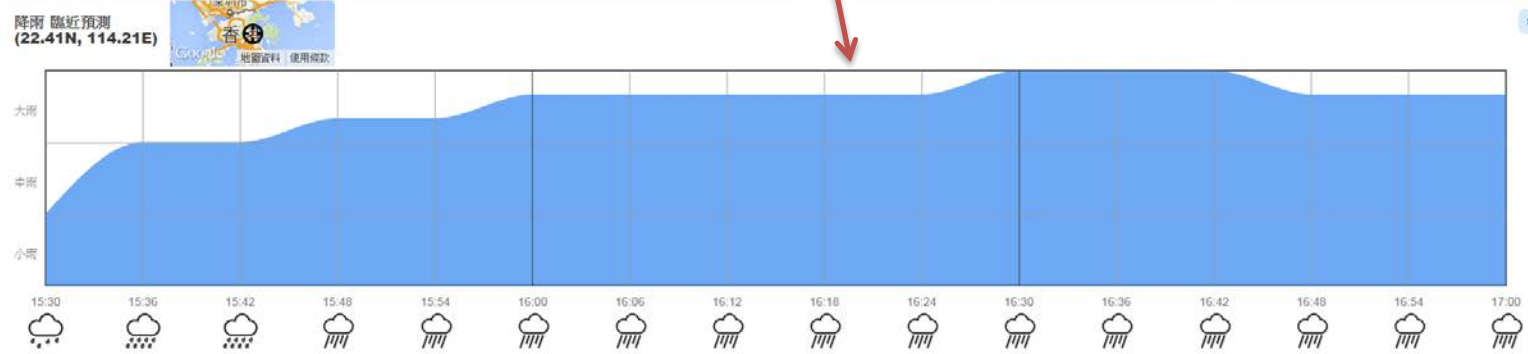
- Internet website :
<http://www.weather.gov.hk/nowcast/prd/api/>
- forecast rainfall maps over the Pearl River Delta region in the next 2 hours
- updated every 12 min
- downloadable as KML files



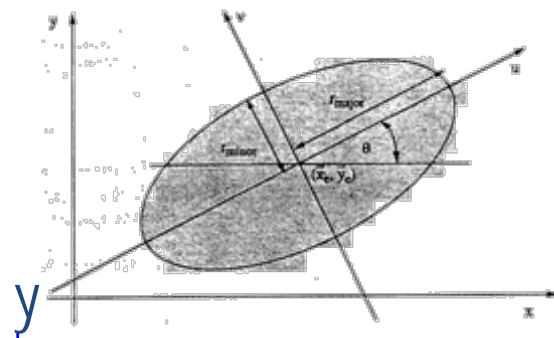
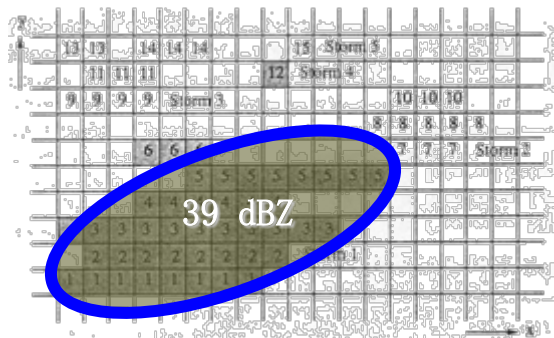
Rainfall Nowcast



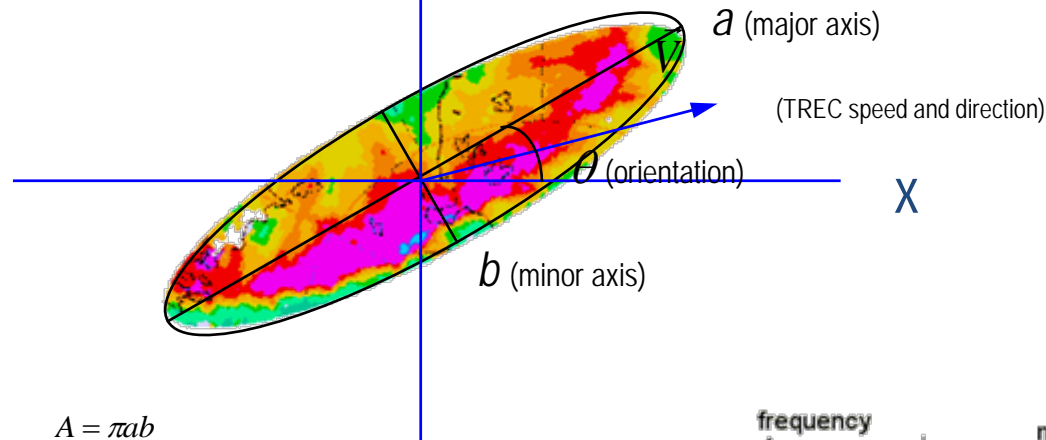
Provide image and animation sequence of rainfall forecast map over HK and Pearl River Delta for the next 2 hours



Cell Tracking in SWIRLS

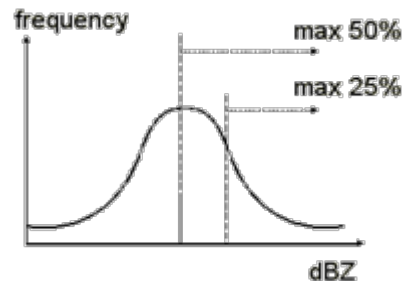


Group echo identification



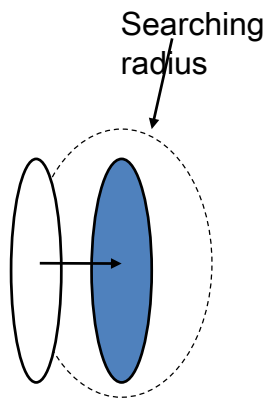
area $A = \pi ab$
 eccentricity $\varepsilon = \sqrt{a^2 - b^2} / a$
 perimeter $P = 4aE(\pi/2, \varepsilon)$
 orientation $\theta = \tan^{-1}(b/a)$
 total intensity $I = \sum_{\text{ellipse}} dbZ \times \Delta A$

max dBZ <--> max rainfall
 ave dBZ <--> ave rainfall
 ave (max50% rainfall)
 ave (max25% rainfall)

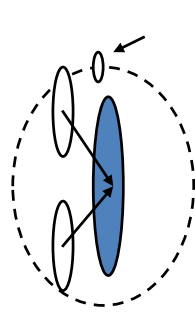


Tracking Capabilities

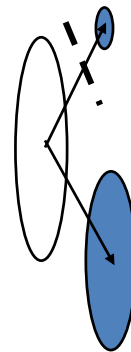
Based on moving speed, size, overlapping area



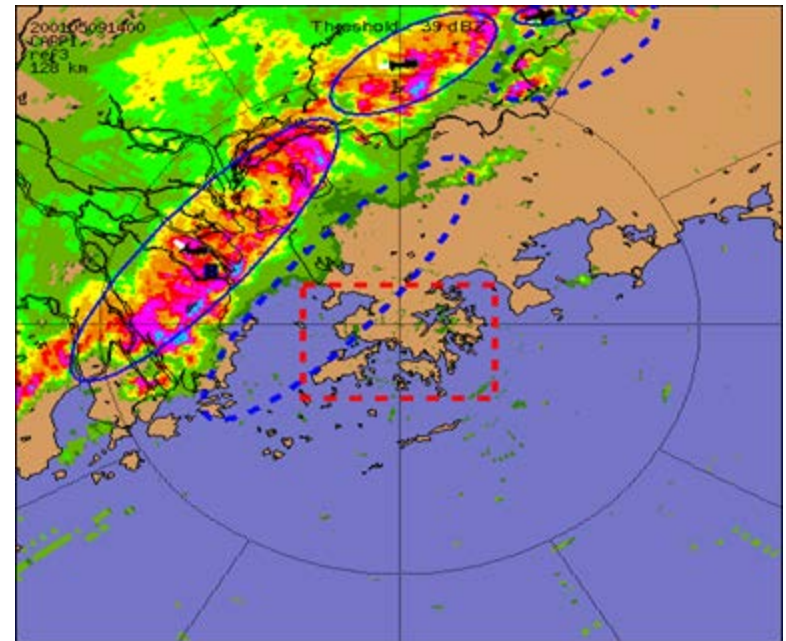
translation



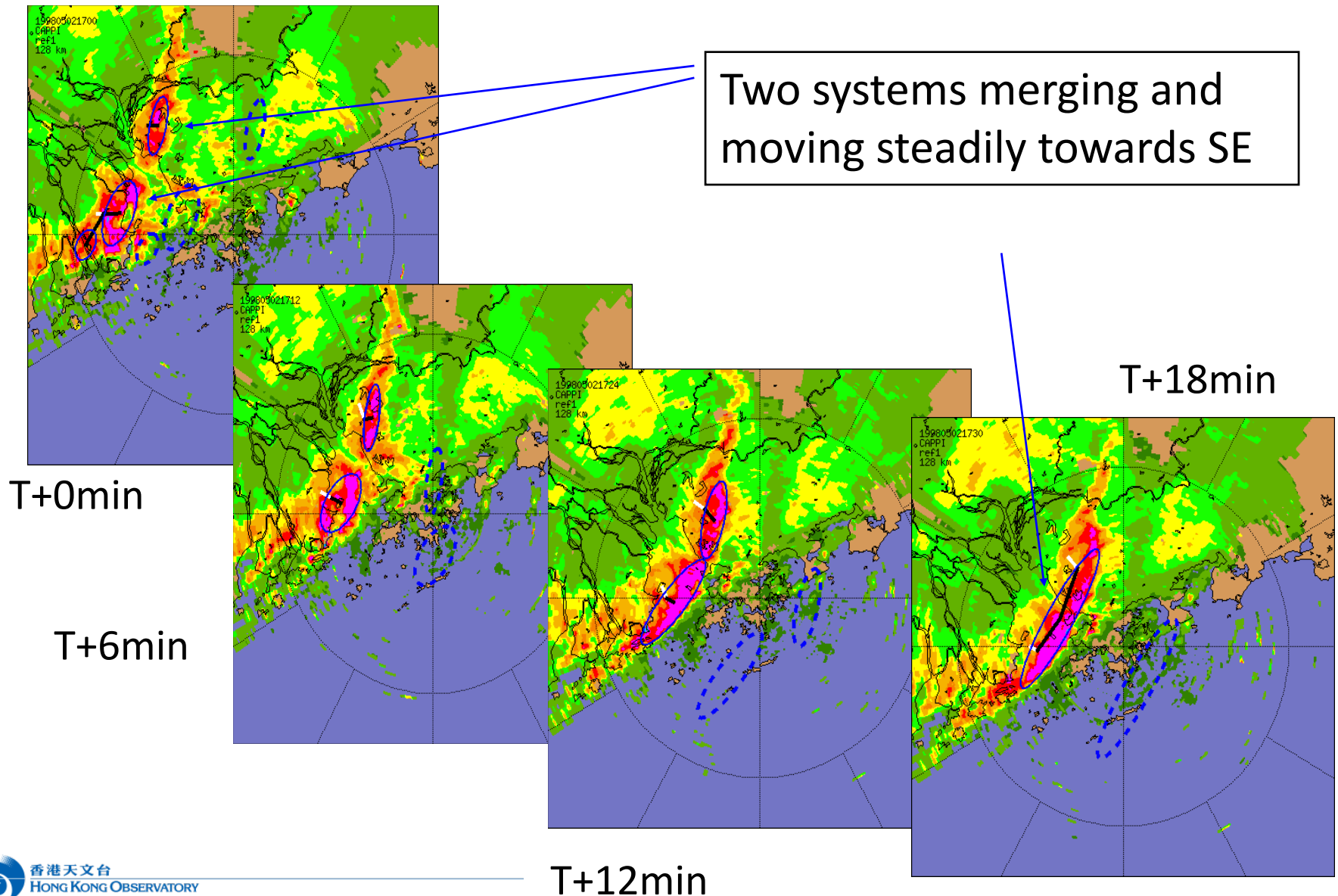
merging



splitting



Application to squall-line



Lightning Conceptual Model

- +/-ve charges carried by ice and graupel respectively
- charges separated vertically by updraft
- Important distribution in the mixed layer from 0°C to -20°C:

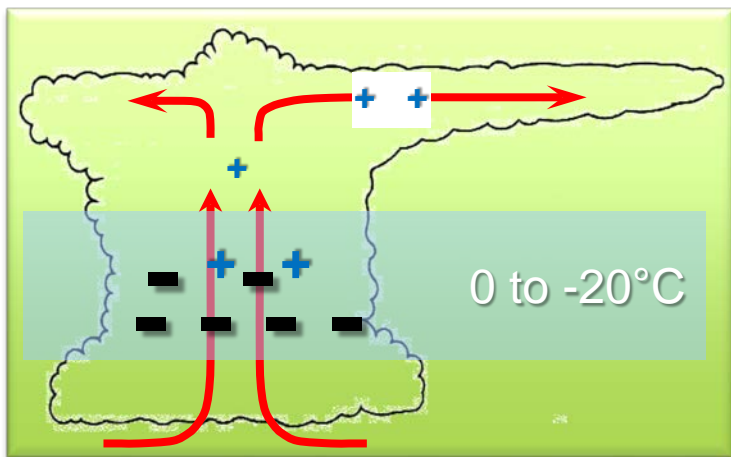


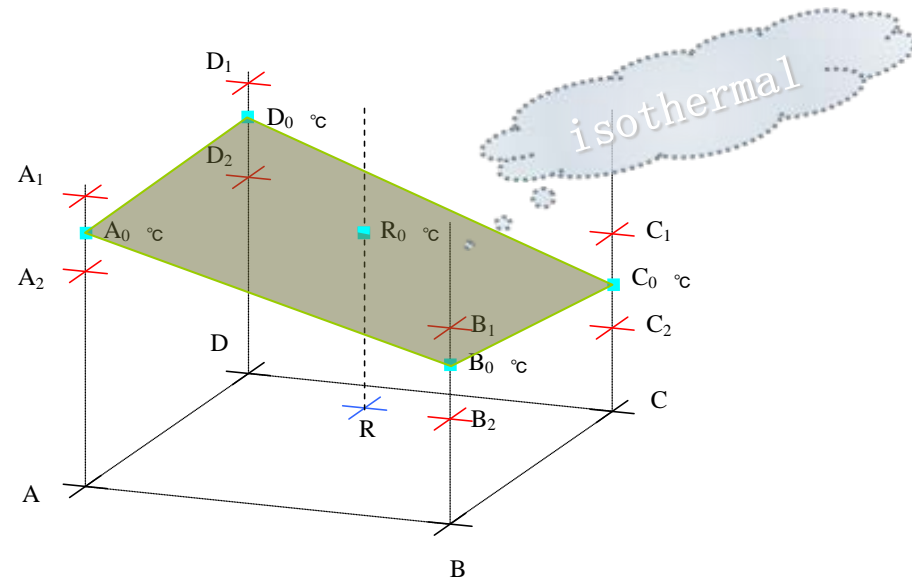
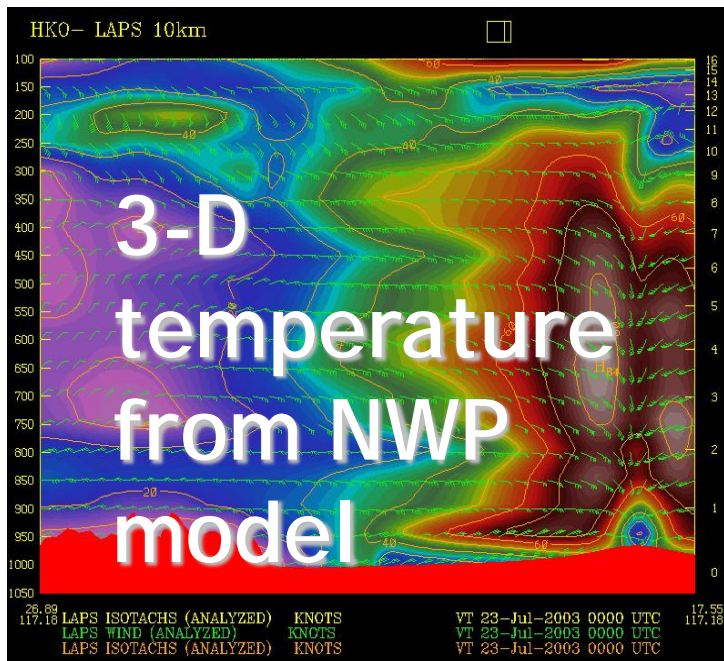
Table II – Summary of the conceptual model for lightning initiation.

Isothermal Layers	(i) Shallow Cu			(ii) Towering Cu			(iii) mature Cb			(iv) decaying Cb		
	D	H	E	D	H	E	D	H	E	D	H	E
below -40°C							↑	*	ρ	↑	*	ρ
-20 to -40°C				↑	*	ρ	↑	*	ρ	↑	*	ρ
-10 to -20°C	↑	*		↑↓	*△	σ	↑↓	*△	σ		*	
0 to -10°C	↑	☾		↑	*☾		↑↓	*△☾			*	
above 0°C	↑	☾		↑	☾		↑↓	△☾	σ	↓	△	
near surface	→←			→←	▽		←→	▽	⊠	←→	▽	⊠

Note : Headings D, H and E stand for vertical dynamics, hydrometeors and electric charges respectively. Other symbols are explained in the main text of Section 2.

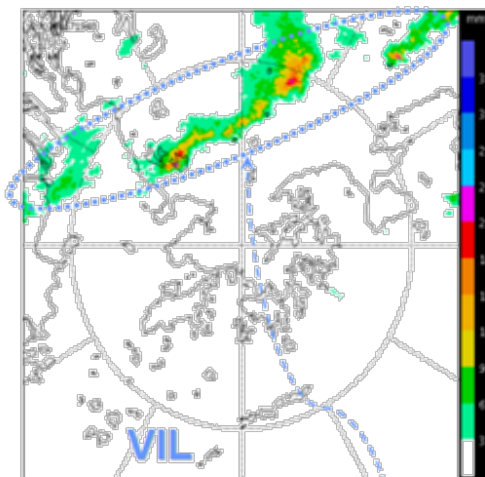
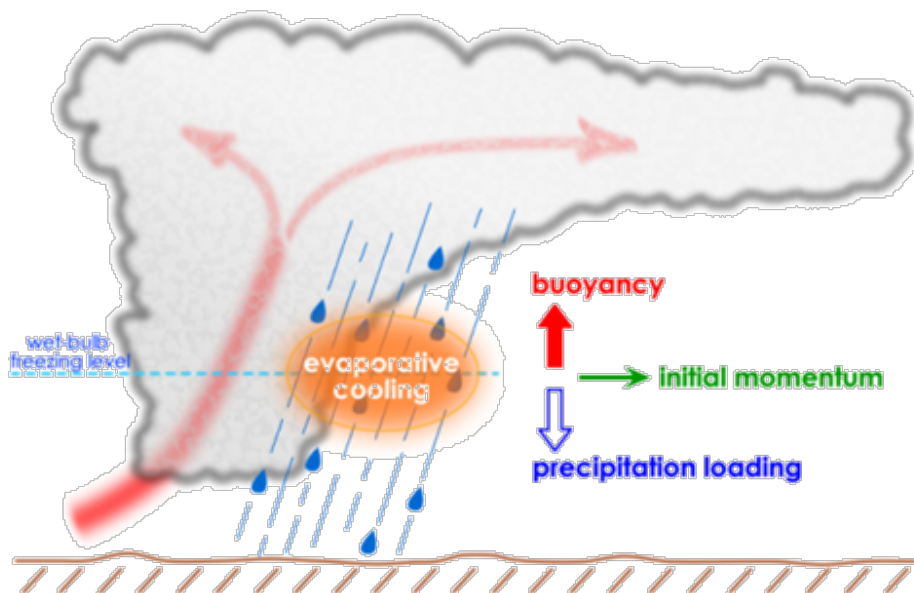
Isothermal Reflectivity

- 3D temp & height fields from hourly-updating model analysis
- interpolate to radar grid (cartesian)
- interpolate reflectivity to isothermal levels



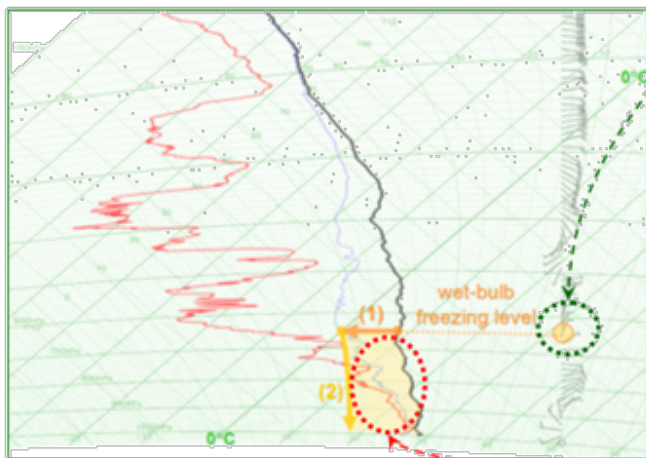
Downburst Conceptual Model

Conceptual model of convective downdraft due to raindrops evaporative cooling of air parcel in the rain shaft



Vertically integrated liquid (VIL) water data derived from radar reflectivity data.

Tephigram with a positive Downdraft Convective Available Potential Energy (DCAPE, the yellowish shaded area). Process (1) isobaric cooling by evaporation of raindrops; Process (2) pseudo-adiabatic descent if favoured.



$$v_s^2 = U_{\text{BUOY}} + v_H^2 + U_{\text{LOAD}}$$

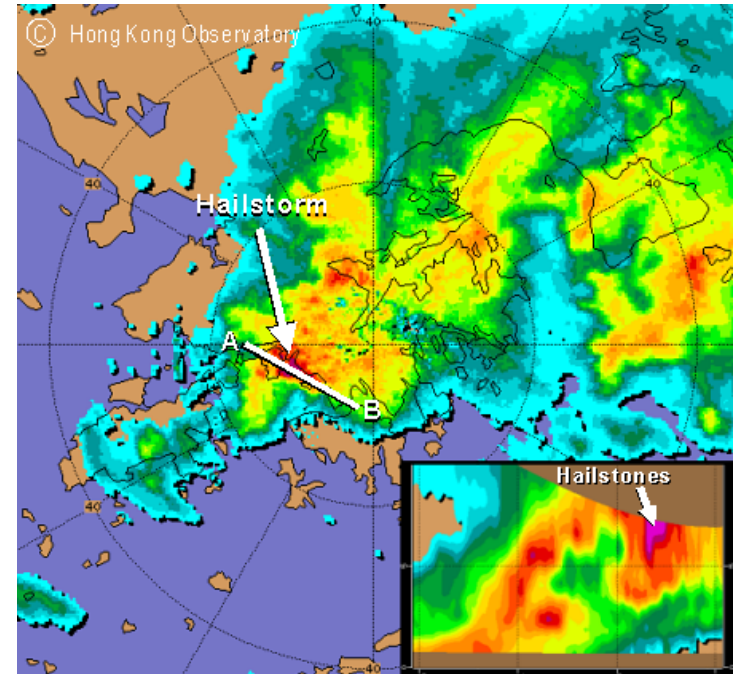
buoyancy
initial mom.
precip. loading

$$U_{\text{BUOY}} = \min \left\{ \int_{p_s}^{p_0} R_d [T_r^{(\text{ambient})} - T_r^{(\text{parcel})}] d \ln p, v_{\text{max}} \right\}$$

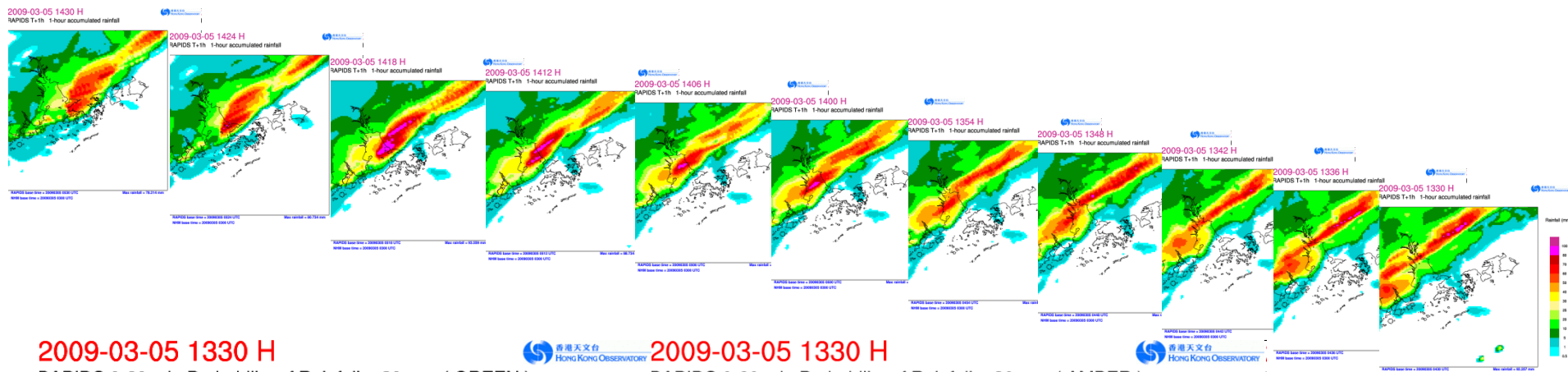
$$U_{\text{LOAD}} = -2 \int_0^H L dz = 2g \int_0^H r_l dz = 20.3 \times \text{VIL}$$

Other Severe Weather Nowcast Algorithms

- Hail
 - 60-dBZ TOPS > 3 km
 - 0-2km VIL < 5 mm
- probability of precipitation
 - Time-lagged ensemble of blending QPF
- probability of lightning threat
 - time lagged ensemble of extrapolated sub-zero reflectivity fields based on optical flow

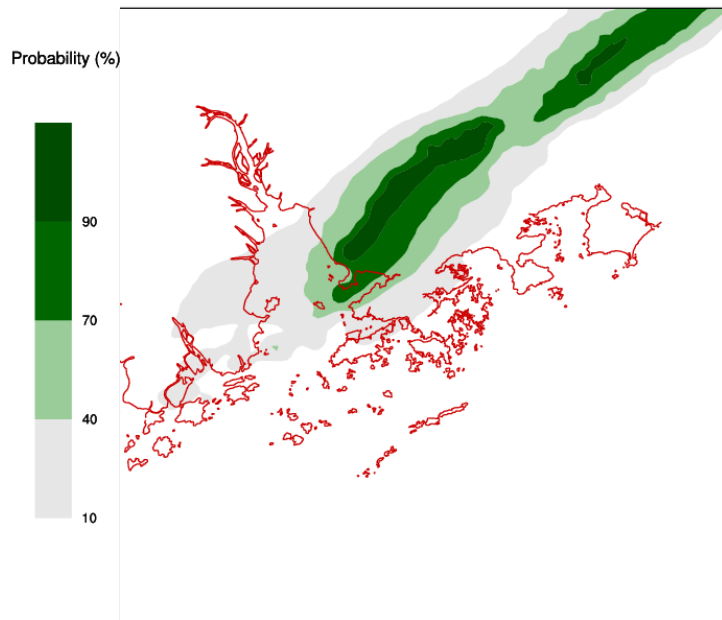
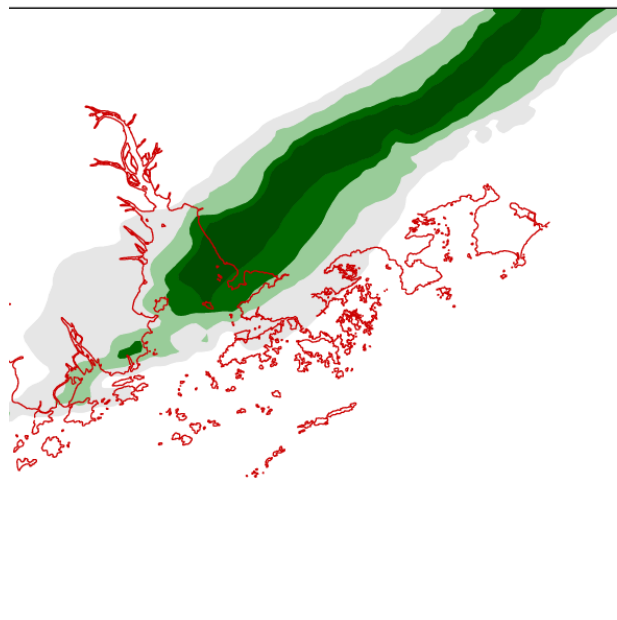


PoP by Time-lagged Ensemble



2009-03-05 1330 H
RAPIDS 0-60 min Probability of Rainfall > 20mm (GREEN)

2009-03-05 1330 H
RAPIDS 0-60 min Probability of Rainfall > 30mm (AMBER)

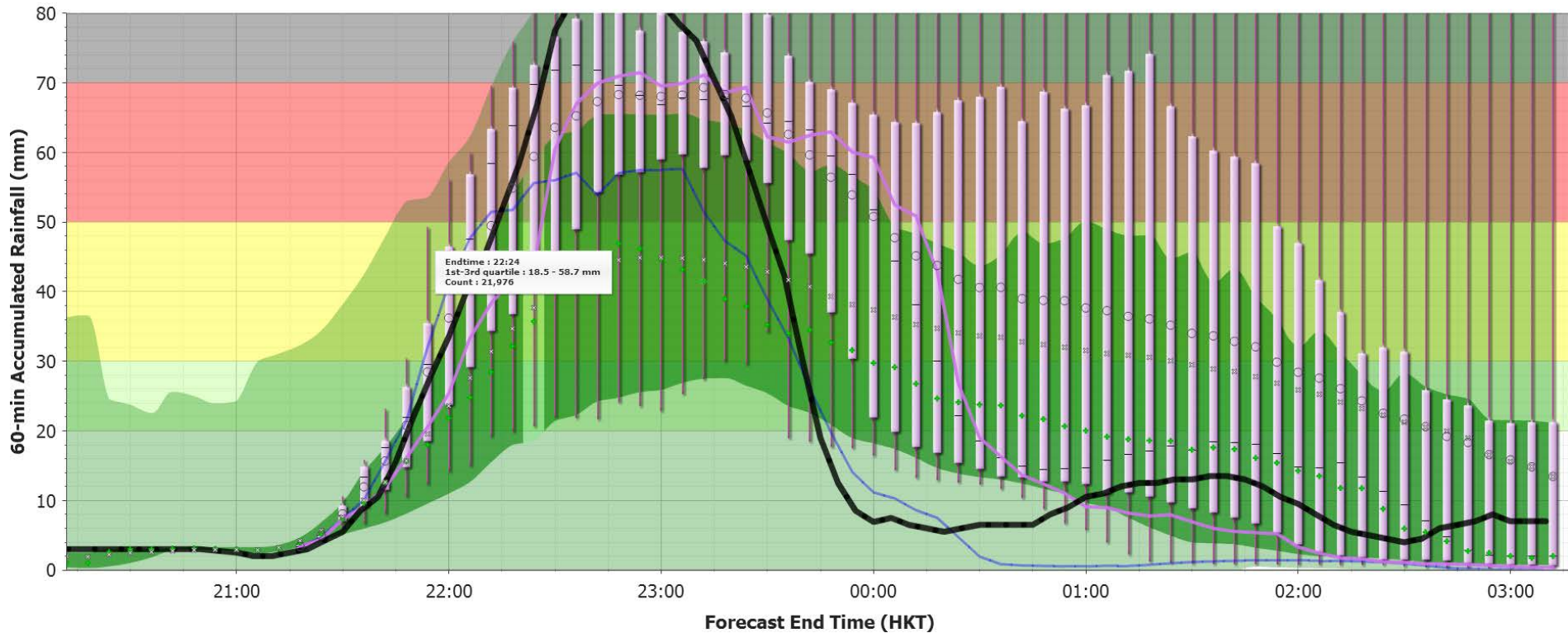


Aggregate latest 10 RAPIDS QPF according to exponential decreasing weights

Probabilistic nowcast of precipitation SWIRLS Ensemble Rainstorm Nowcast (SERN)

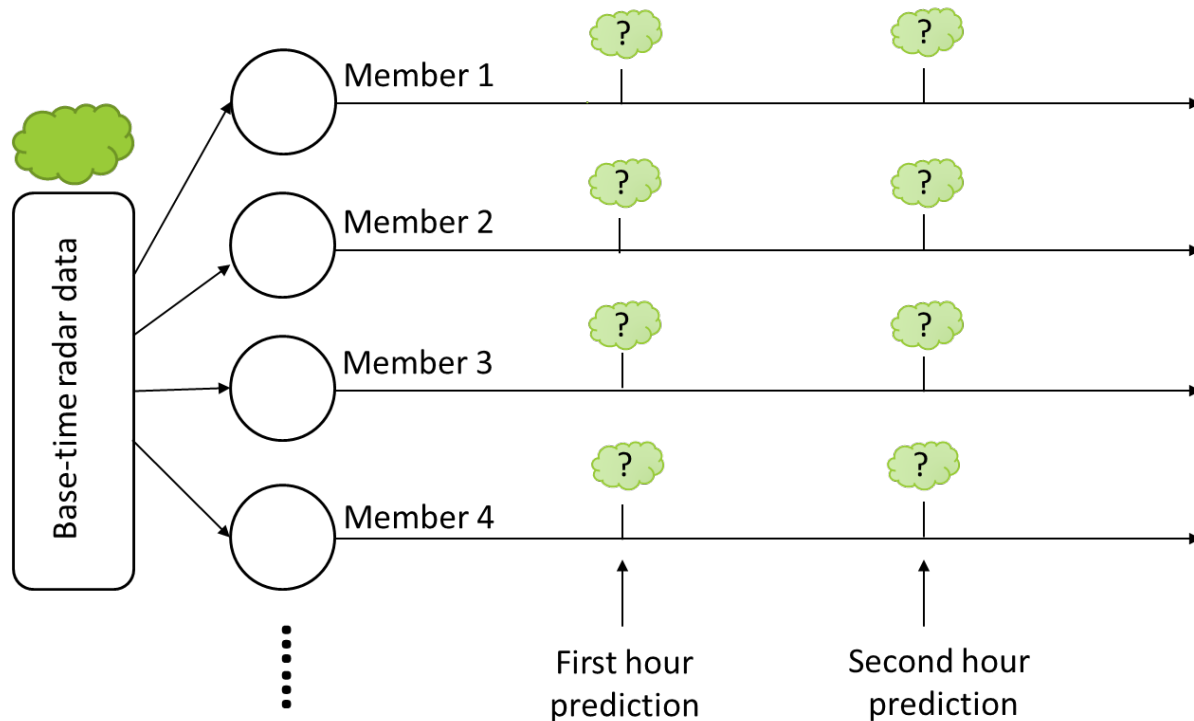
Spread of radar rainfall nowcast via selecting various parameters in echo motion retrieval

SWIRLS Ensemble Rainstorm Nowcast (28 + time-lagged members) at 2014-05-08 21:12 HKT
Time Evolution of the 15-th Ranked Raingauge Rainfall



Design of SWIRLS Ensemble Rainfall Nowcast

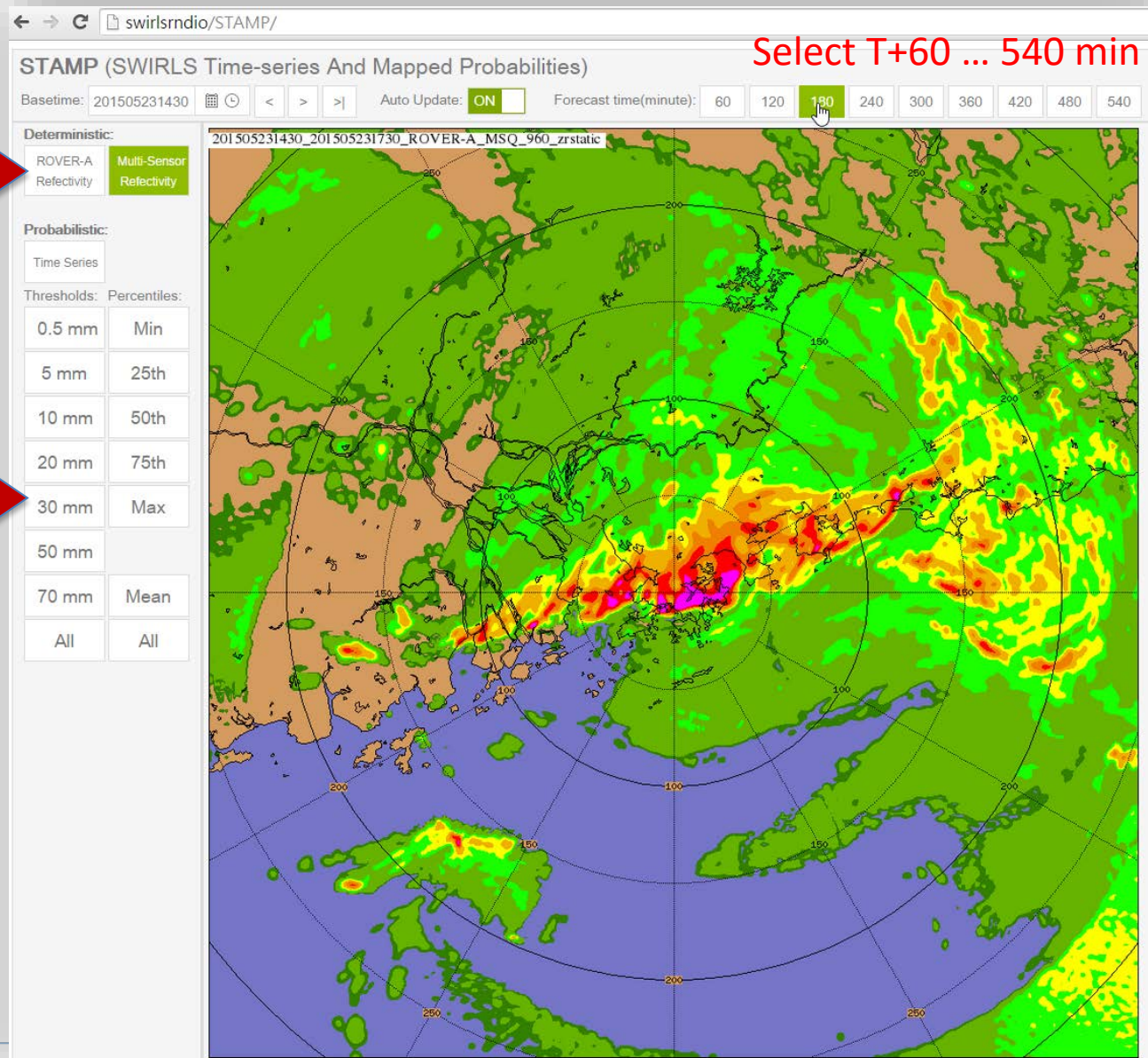
- By tuning parameters in optical flow computation, 36 sets of configurations have been experimented to generate rainfall nowcast ensemble of 36 members.



STAMP - Integrated Display of SWIRLS Deterministic and Probabilistic

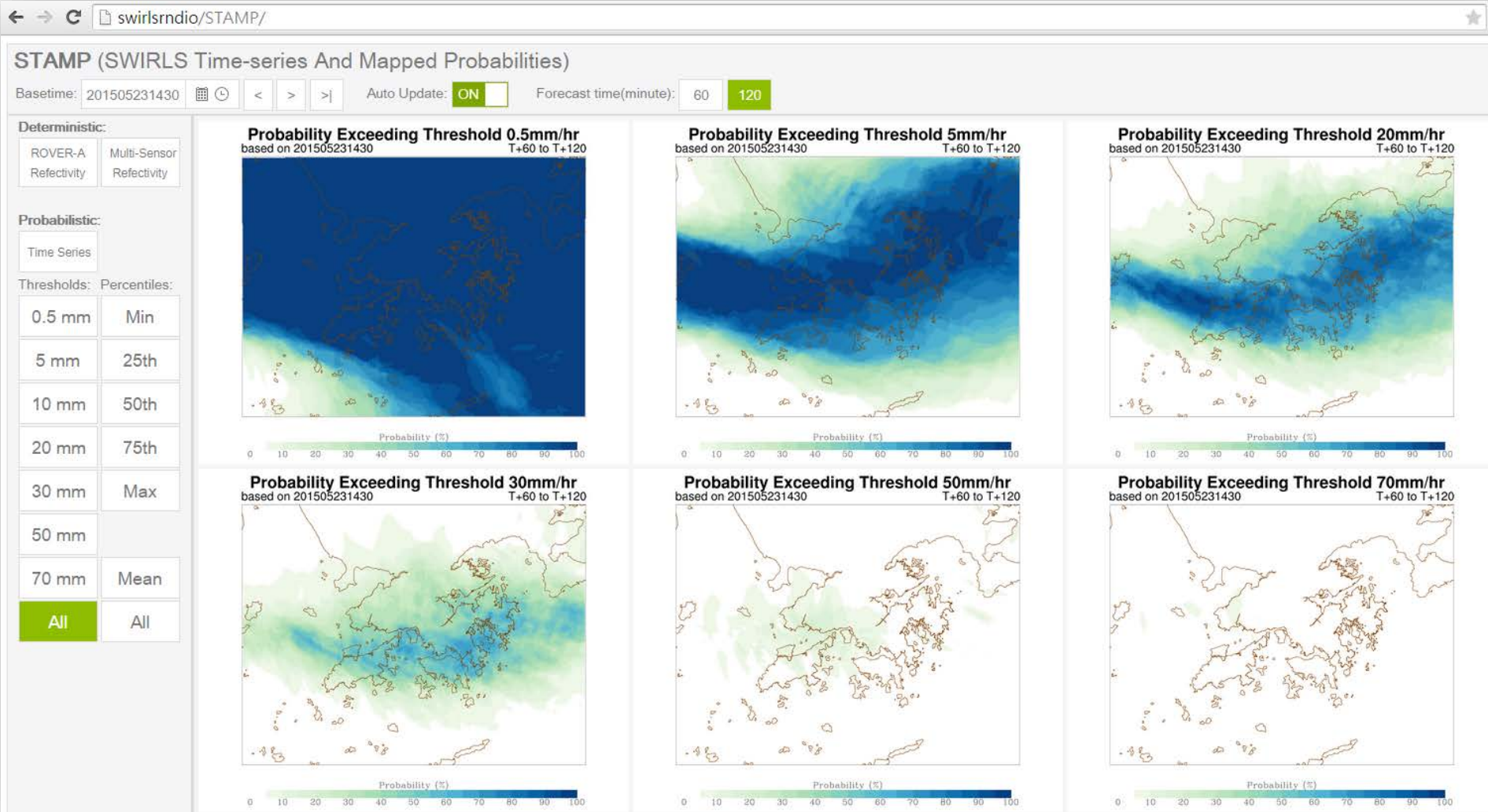
Radar-based / Multi-Sensor Deterministic

Probabilistic Products



Select T+60 ... 540 min nowcast

Probabilities of rainfall exceeding 0.5/5/20/30/50/70 mm per hr



Precipitation at different percentiles

swirlsrndio/STAMP/

STAMP (SWIRLS Time-series And Mapped Probabilities)

Basetime: 201505231430



Auto Update: ON

Forecast time(minute):

60

120

Deterministic:

ROVER-A
Reflectivity

Multi-Sensor
Reflectivity

Probabilistic:

Time Series

Thresholds: Percentiles:

0.5 mm Min

5 mm 25th

10 mm 50th

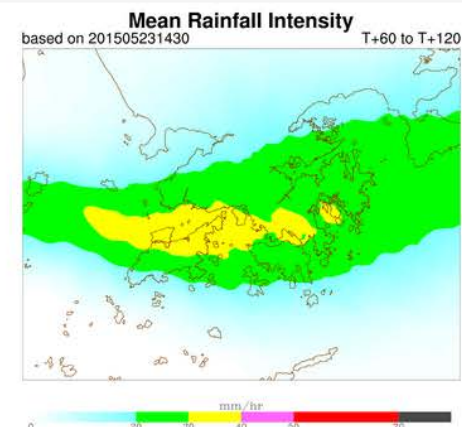
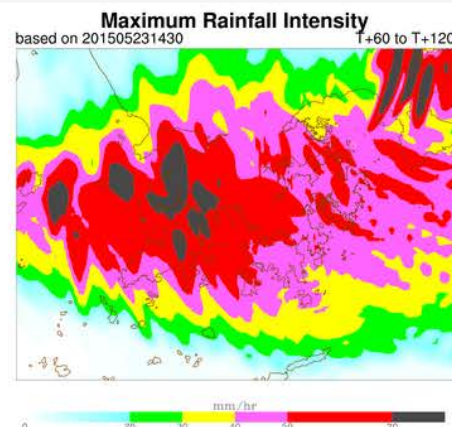
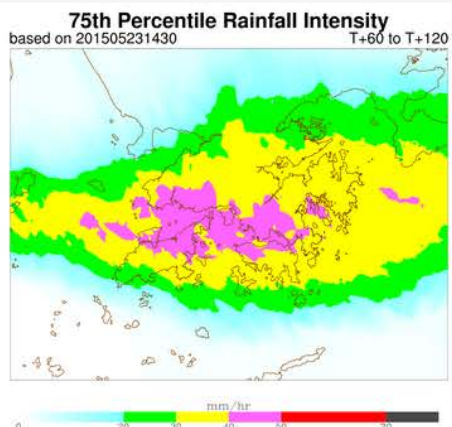
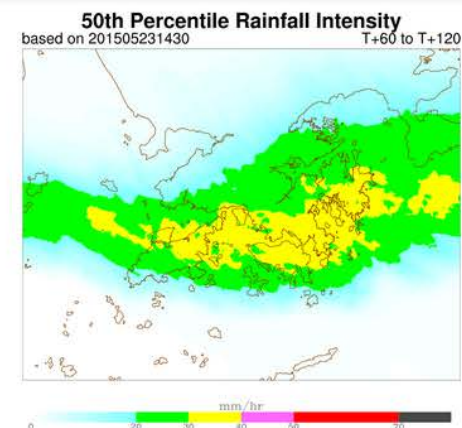
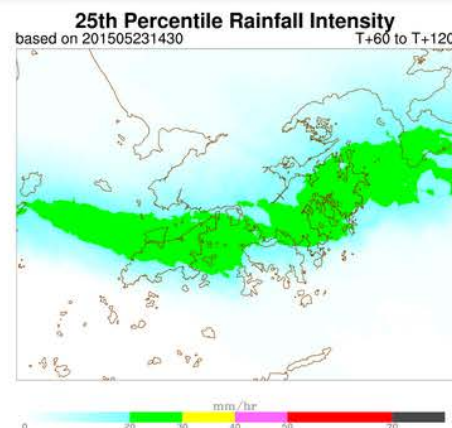
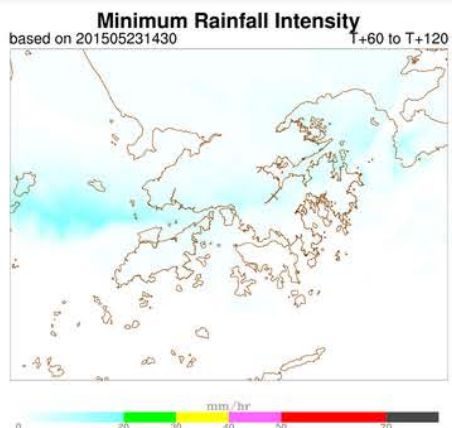
20 mm 75th

30 mm Max

50 mm

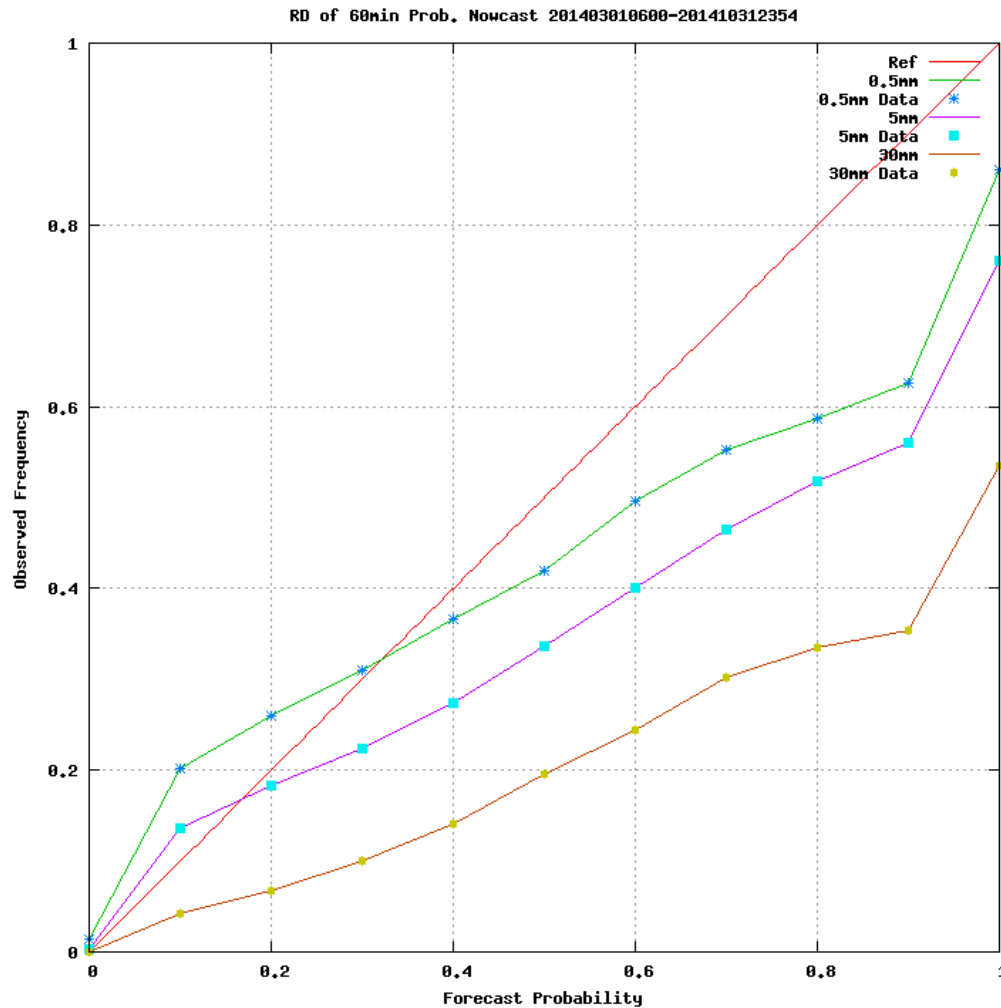
70 mm Mean

All All



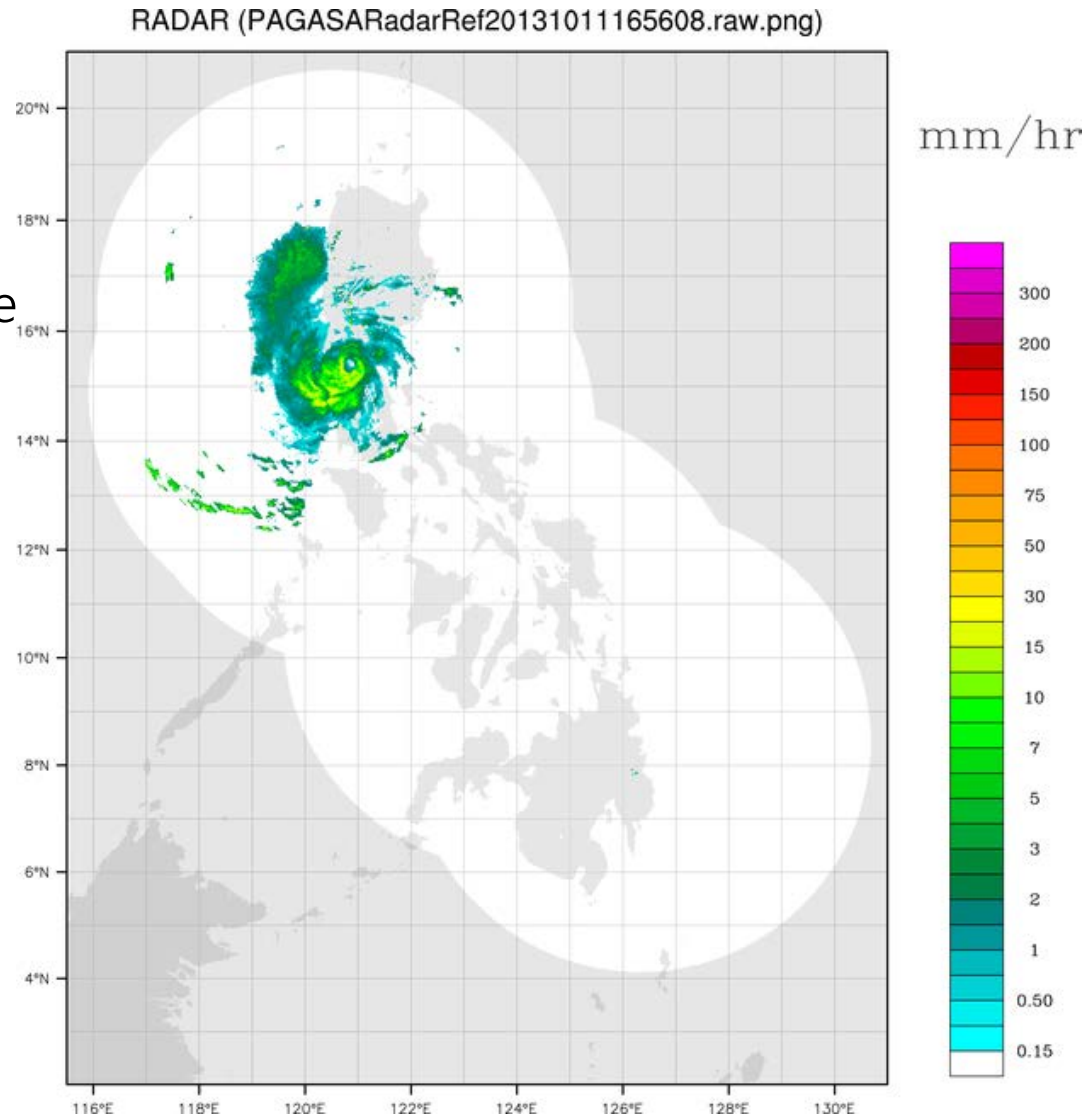
Reliability diagram (1-hr rainfall forecast)

Mar – Oct 2014



Collaboration on TC rainfall nowcast

- Radar mosaic from PAGASA
- Attachment programme under ESCAP/WMO Typhoon Committee Research Fellowship Scheme

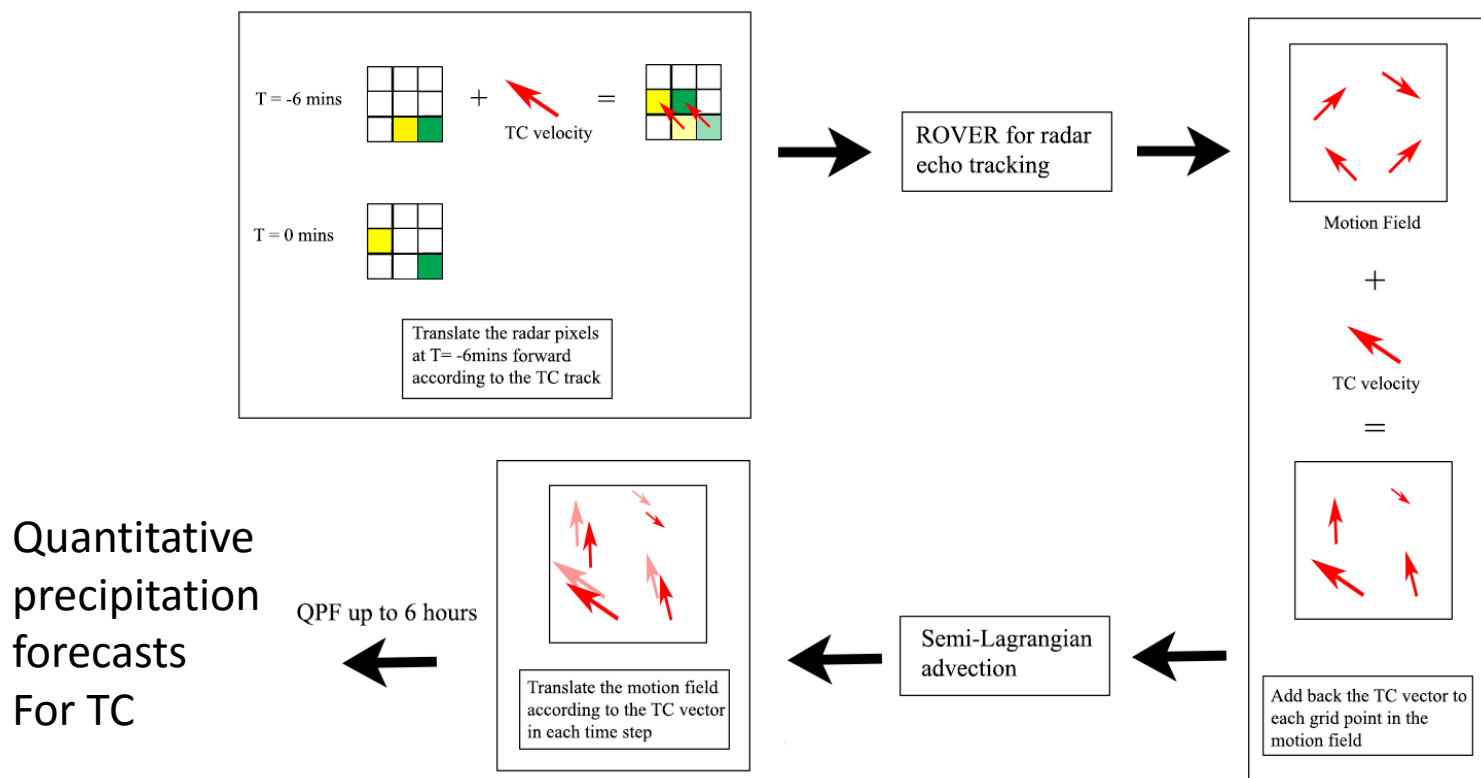


TC Module in SWIRLS

Typhoon Committee Research Fellowship 2012

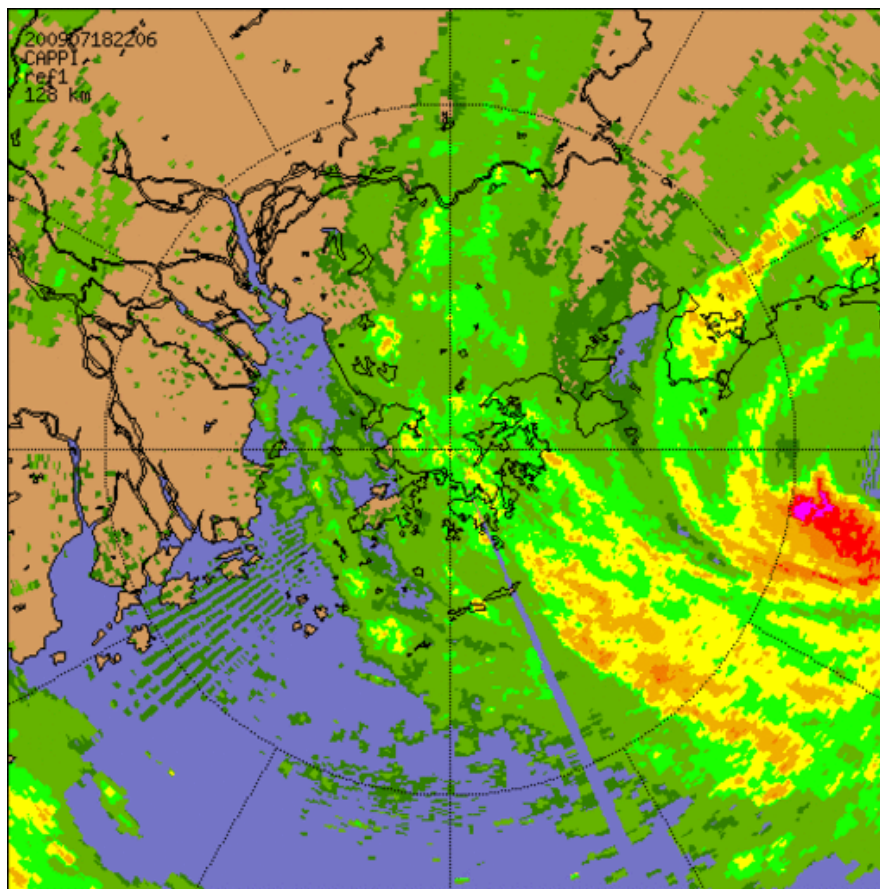
- Enhancement Method:

Separate the motion of TC before radar echo tracking

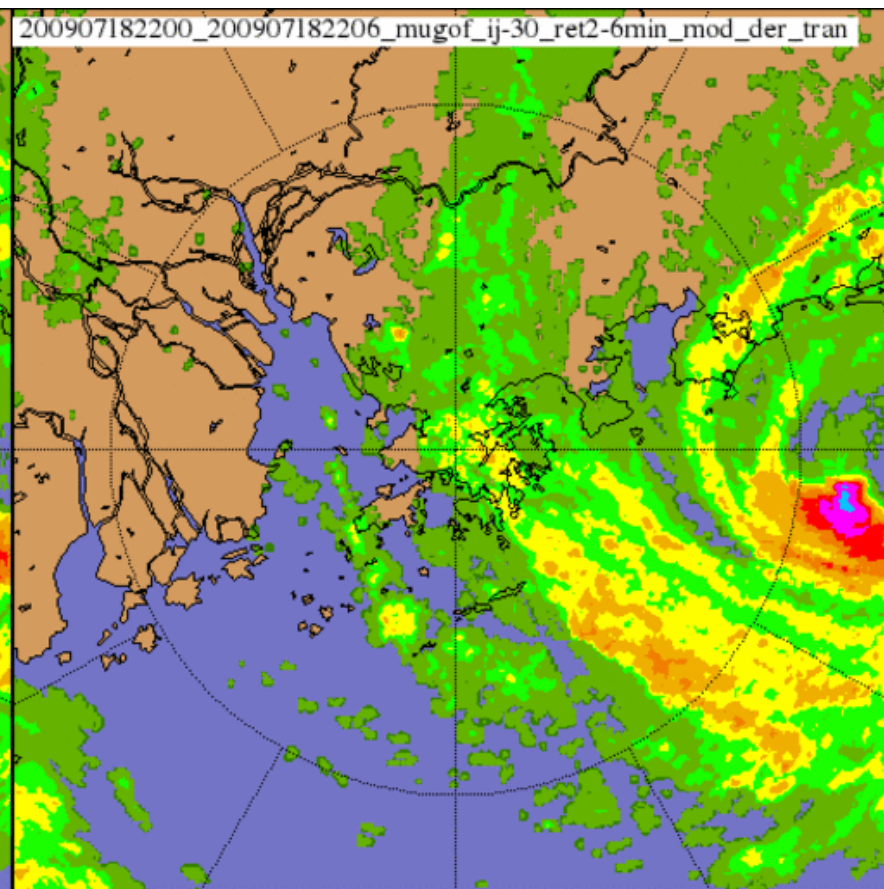


TC Nowcast Module

ACTUAL

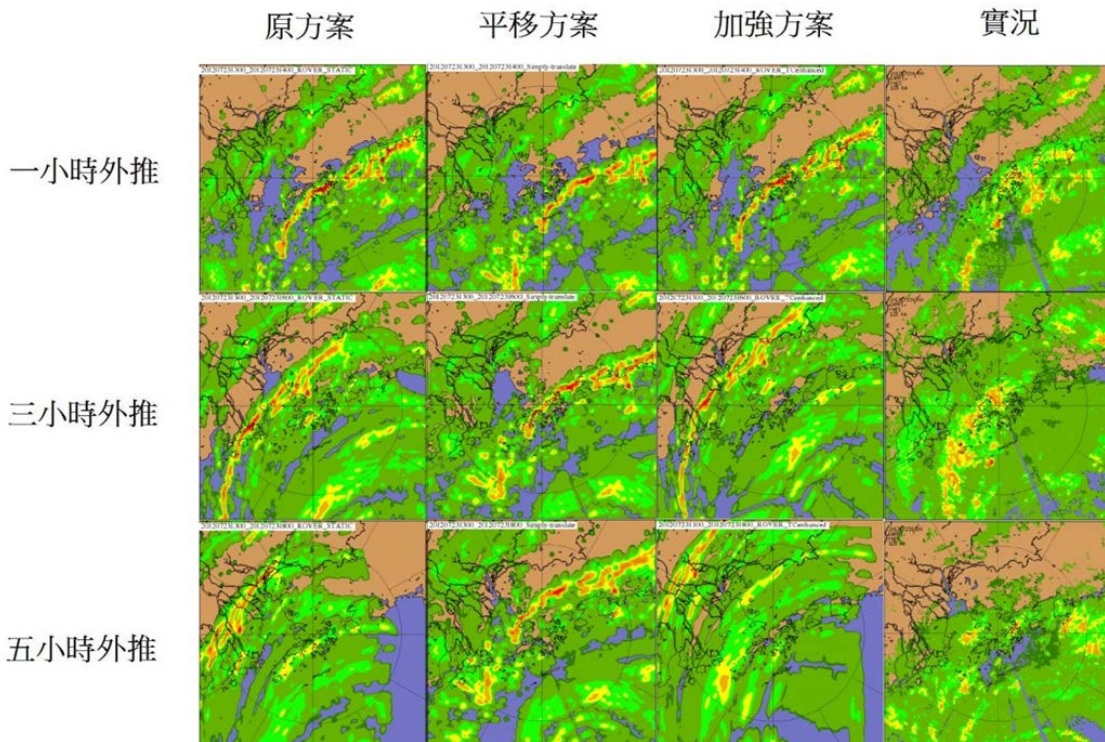


Forecast using TC Module

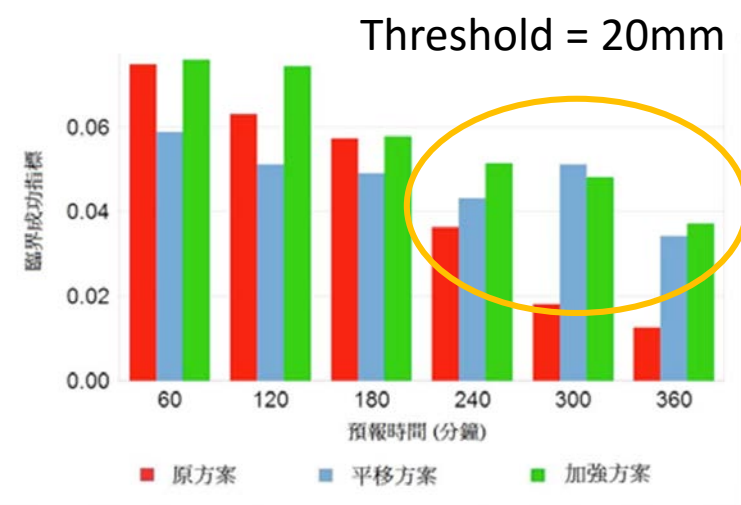
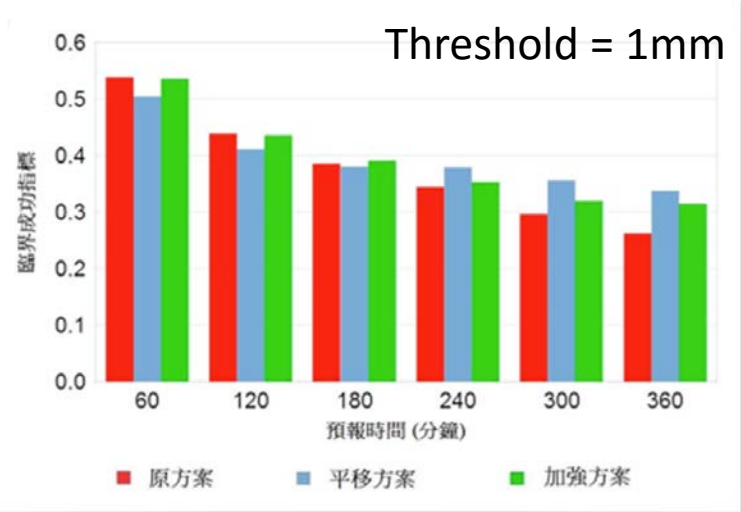


Performance of SWIRLS TC Module

Verification (15 Cases in 2003-2012)



Severe Typhoon Vicente
13HKT on 23 July 2012

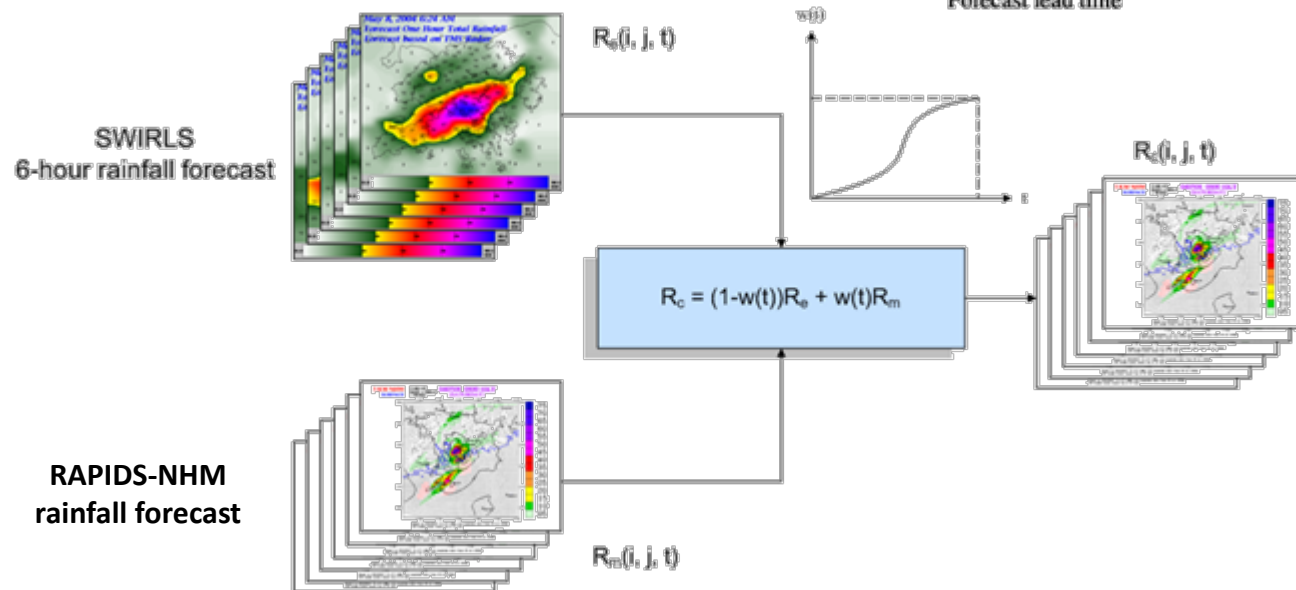
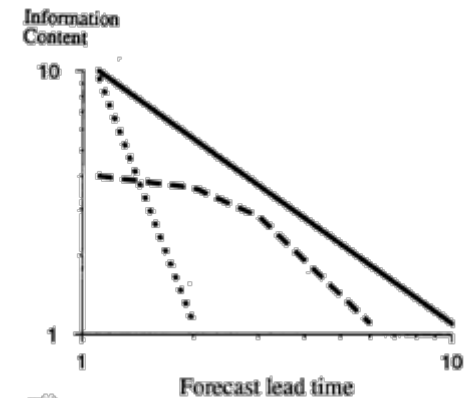


Blending Nowcast with NWP

RAPIDS

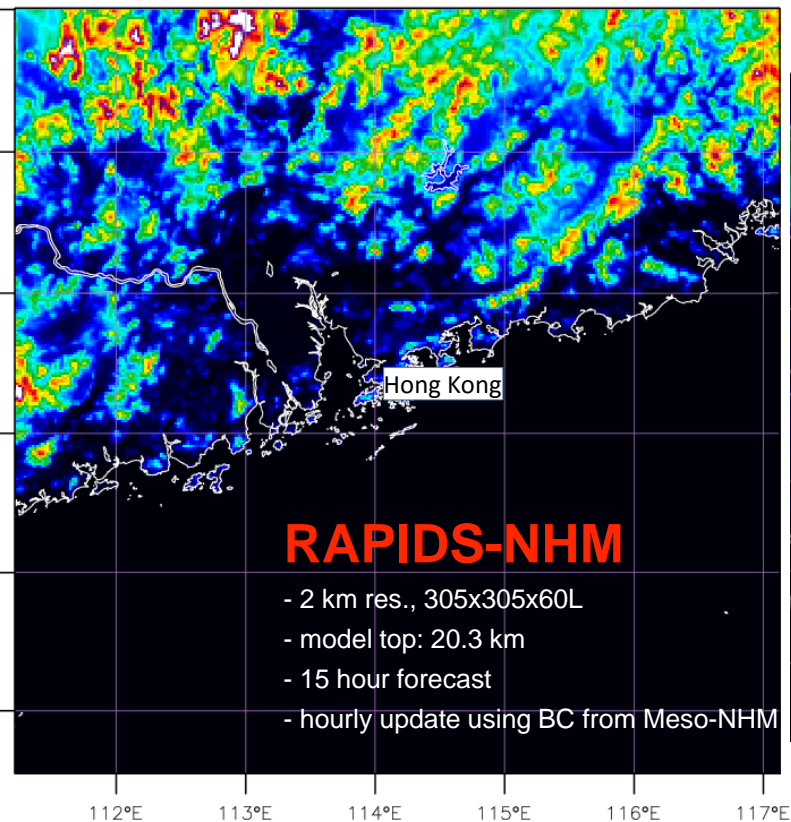
Rainstorm Analysis and Prediction Integrated Data-processing System

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

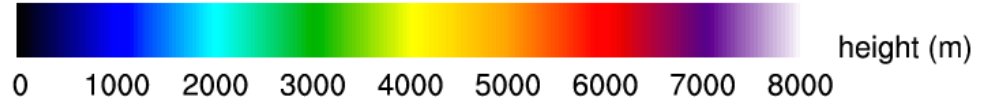
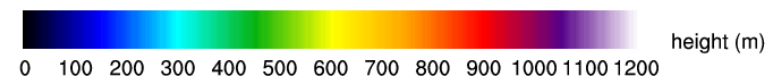
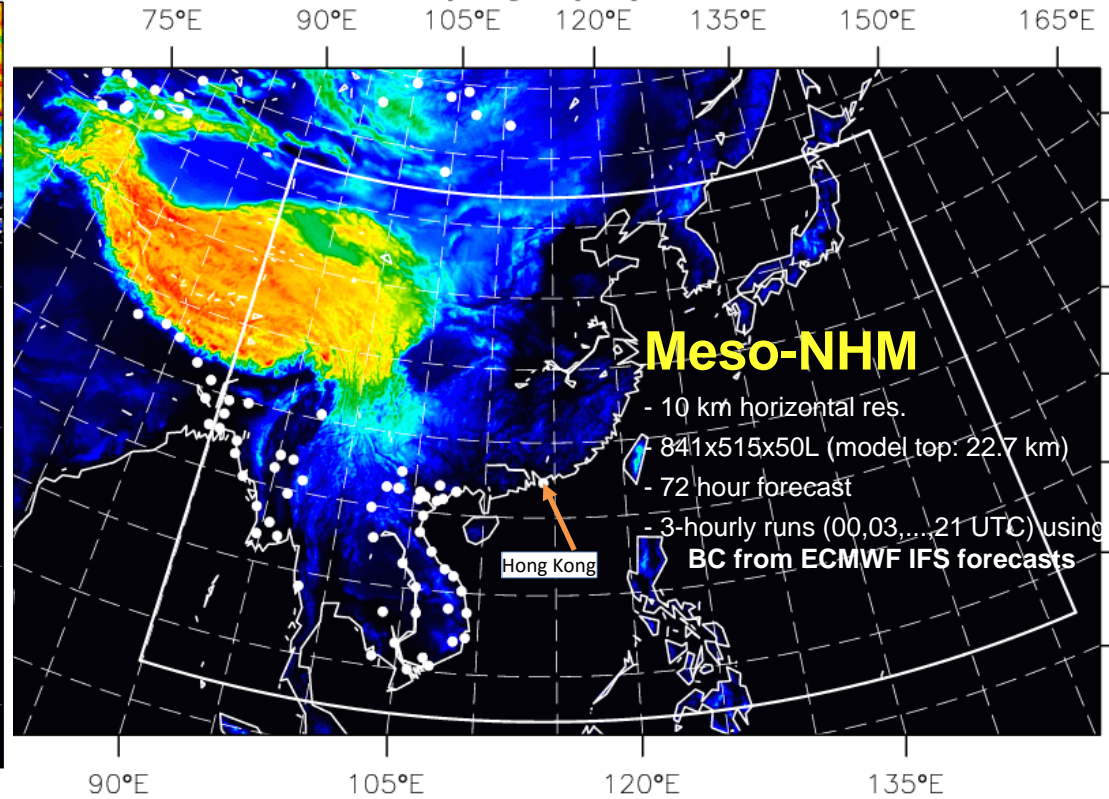


Mesoscale and Convection-permitting NWP System in Hong Kong Observatory

RAPIDS-NHM Topography

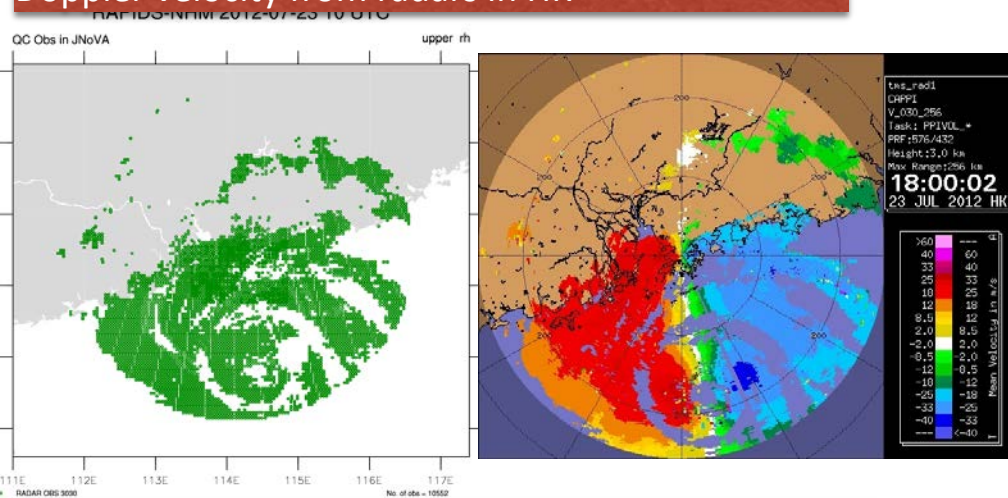


Meso-NHM Topography

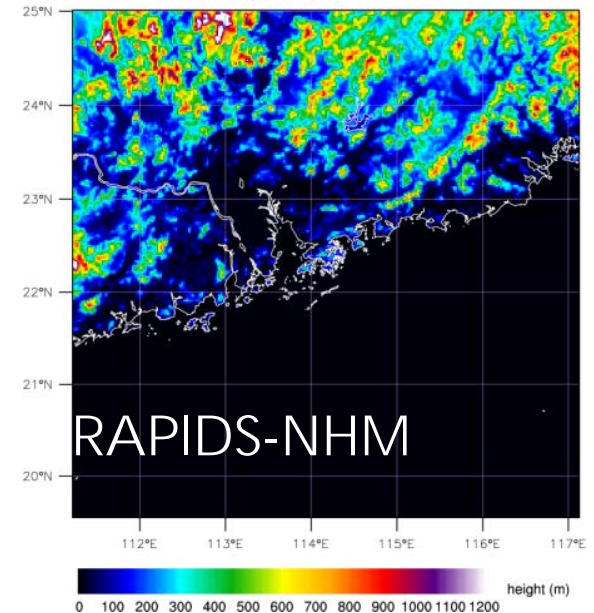


Data Assimilation of Radar Observations in RAPIDS-NHM

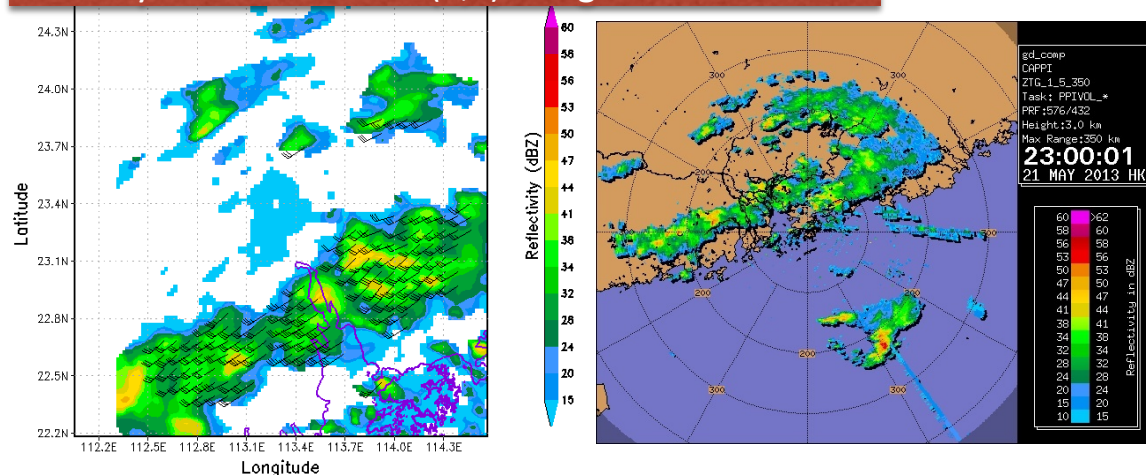
Doppler velocity from radars in HK



RAPIDS-NHM Topography



multi-layer wind retrieval (u,v) using radar mosaic



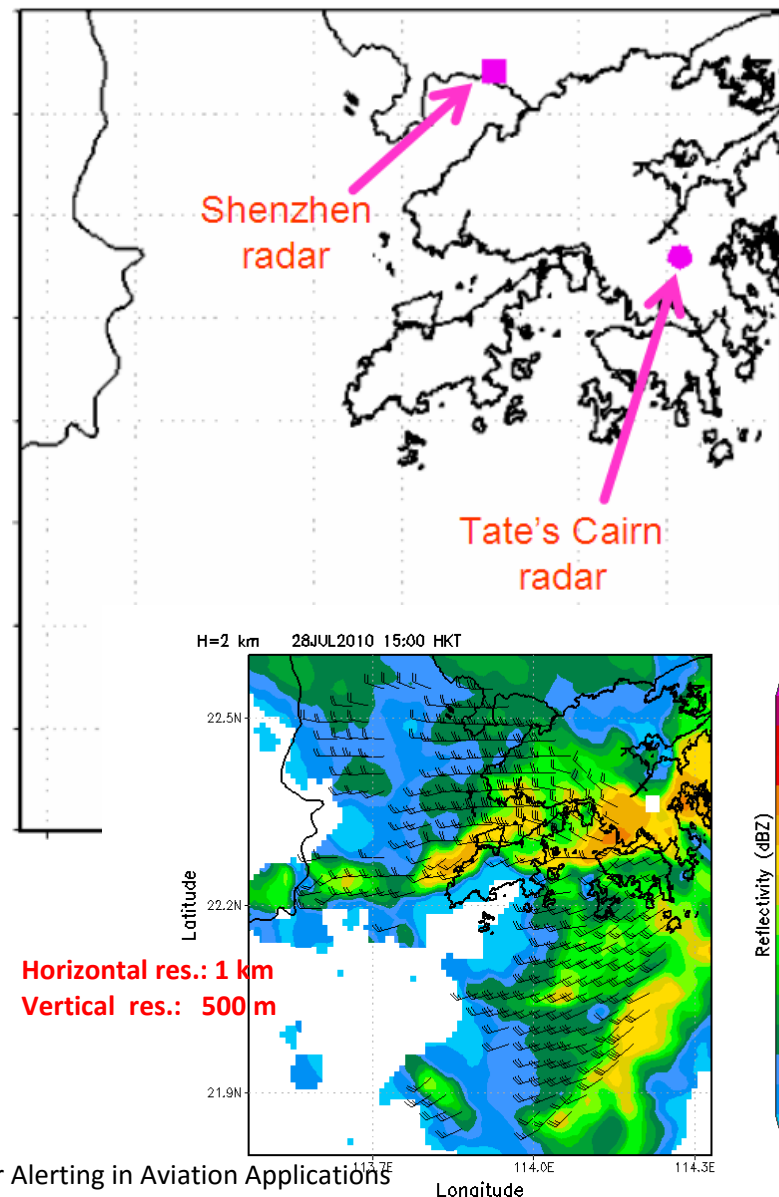
CAPPI reflectivity volume for 1D retrieval
(mosaic from HK + Guangdong radars)

Radar retrieval wind

- Based on Doppler velocity from Hong Kong and radars in Shenzhen and Guangzhou
- Minimization of cost function to obtain (u, v, w) :

$$J = J_O + J_B + J_D + J_S$$

- J_O is proportional to the square of difference between the observed radial velocity and the radial velocity derived from retrieved 3D wind field;
- J_B is proportional to the square of difference between the retrieved 3D wind field and the background;
- J_D is the anelastic mass constraint term; and
- J_S is the smoothness constraint of retrieved wind field using Laplacian of wind components.



Reference:

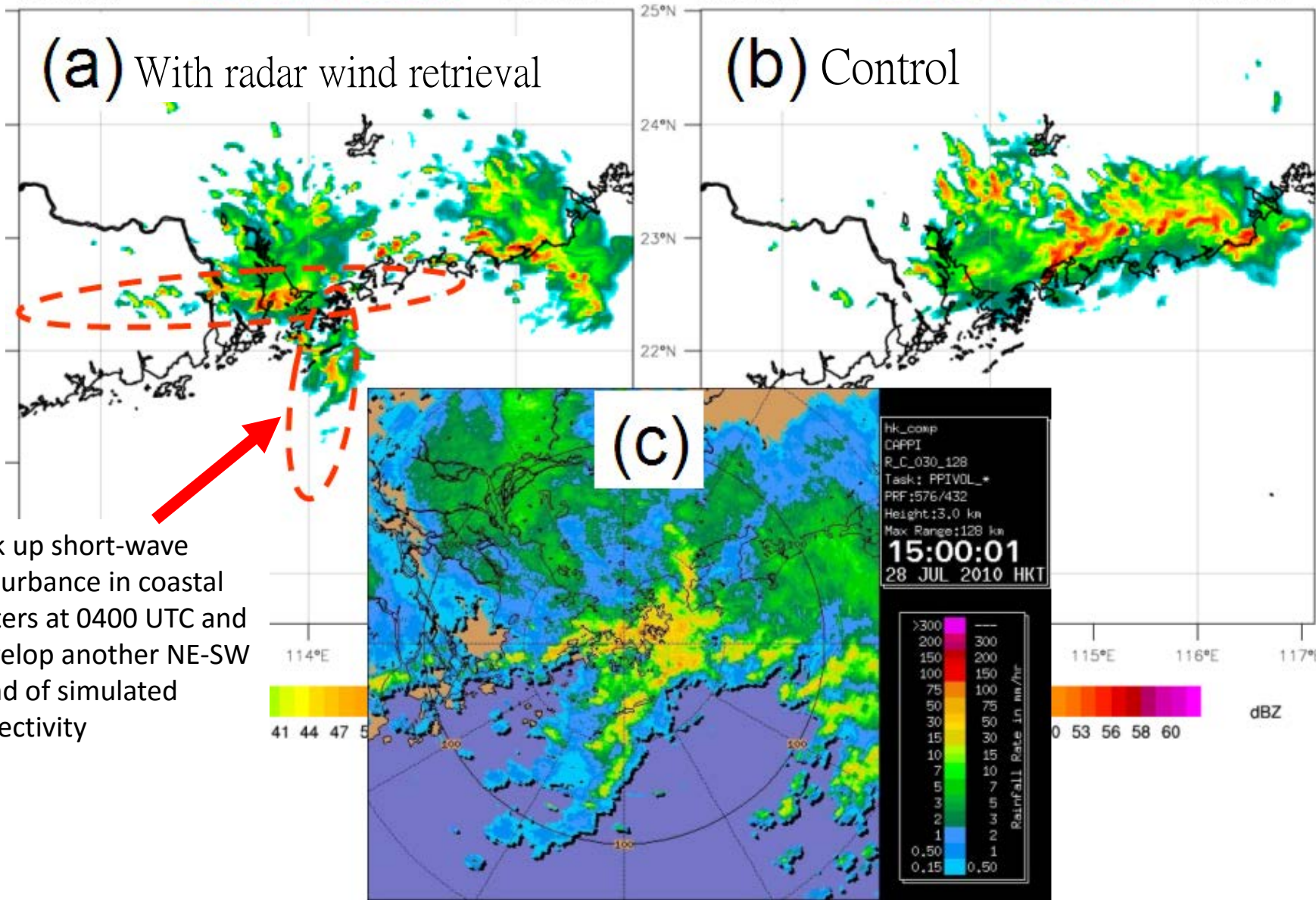
4 hour forecast from RAPIDS-NHM

Forecast Equivalent Reflectivity from RAPIDS-NHM **2010-07-28 16 HKT**

2010-07-28 04 UTC
T+04 h forecast

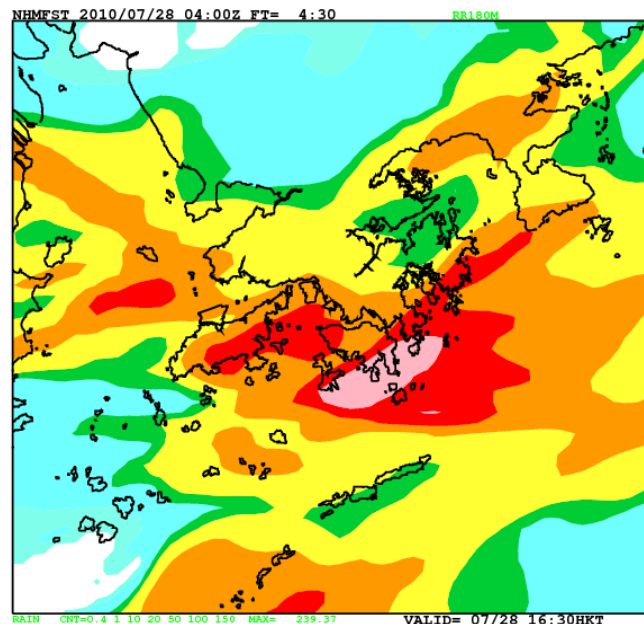
Forecast Equivalent Reflectivity from RAPIDS-NHM **2010-07-28 16 HKT**

2010-07-28 04 UTC
T+04 h forecast

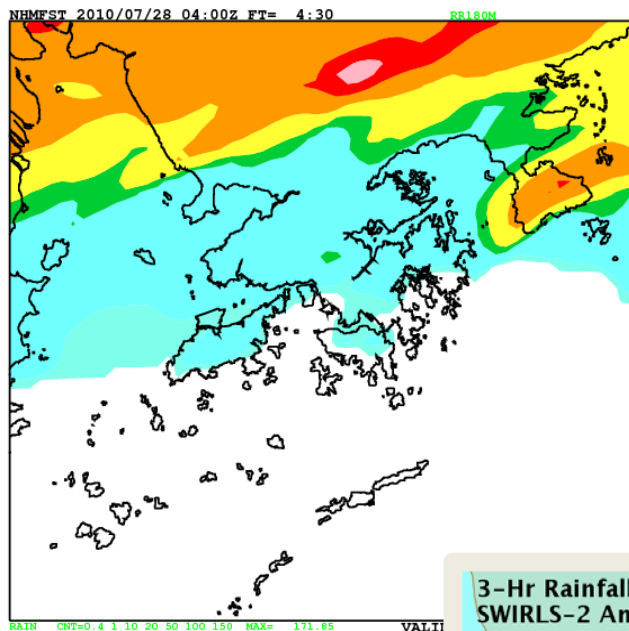


Pick up short-wave disturbance in coastal waters at 0400 UTC and develop another NE-SW band of simulated reflectivity

Impact on QPF

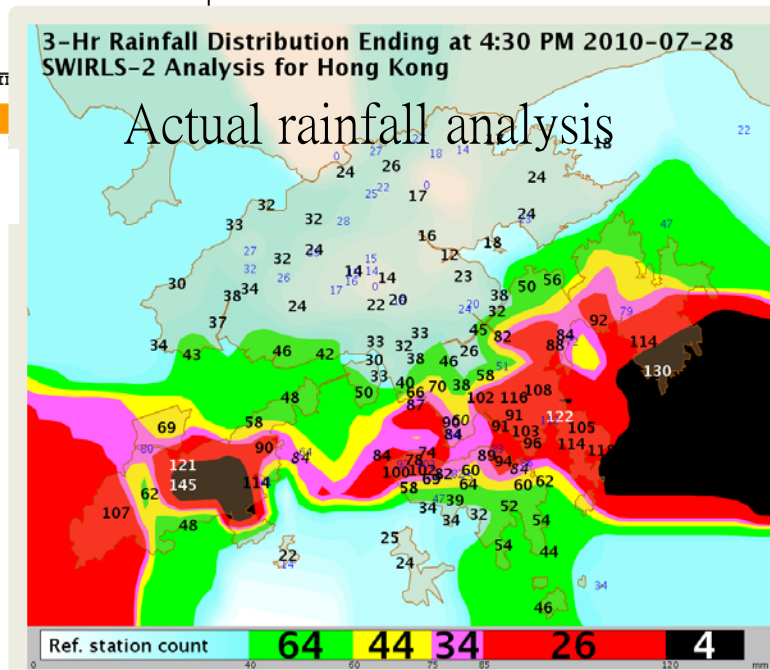


With radar wind retrieval

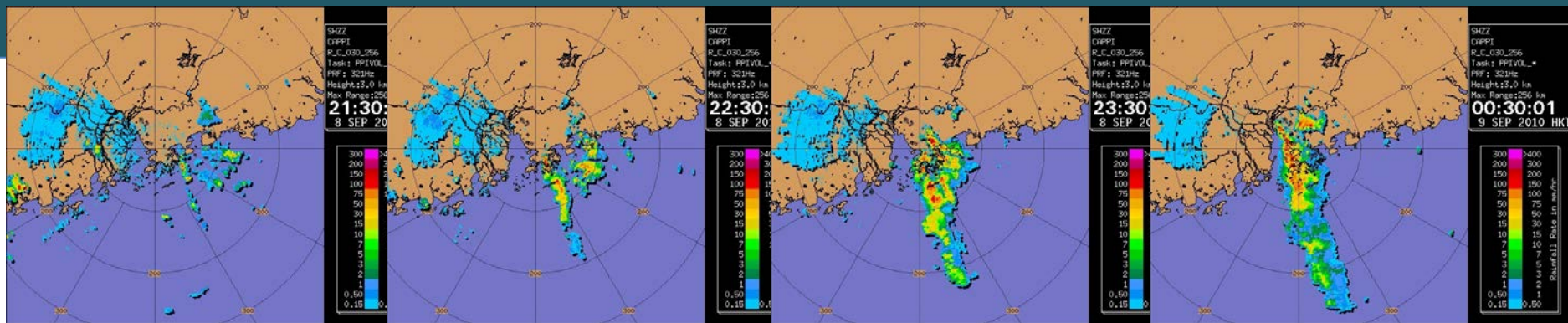


Control Expt (no radar)

RAPIDS-NHM
3-hr acc. rainfall ending at
1630H



Blending Nowcast and NWP



2010-09-09 0030 H

SWIRLS T+6h 1-hour accumulated rainfall

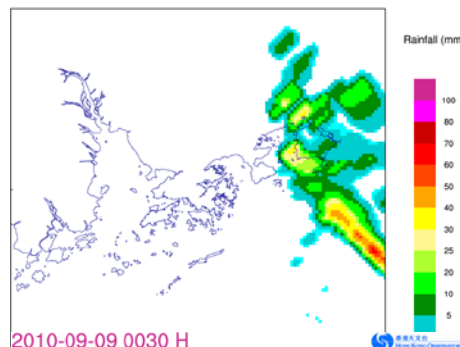
2010-09-09 0100 H

SWIRLS T+6h 1-hour accumulated rainfall

2010-09-09 0100 H

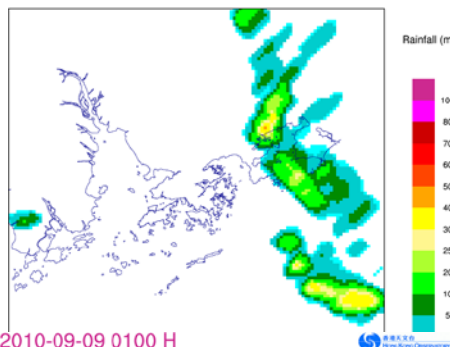
SWIRLS T+5h 1-hour accumulated rainfall

SWIRLS nowcasts
for
00:30 – 01:00H



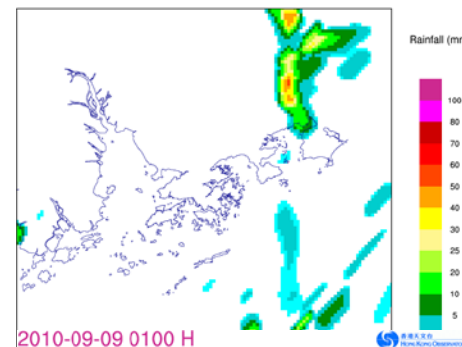
2010-09-09 0030 H

RAPIDS2k T+6h 1-hour accumulated rainfall



2010-09-09 0100 H

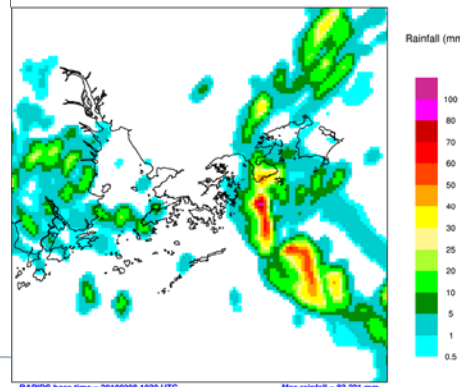
RAPIDS2k T+6h 1-hour accumulated rainfall



2010-09-09 0100 H

RAPIDS2k T+5h 1-hour accumulated rainfall

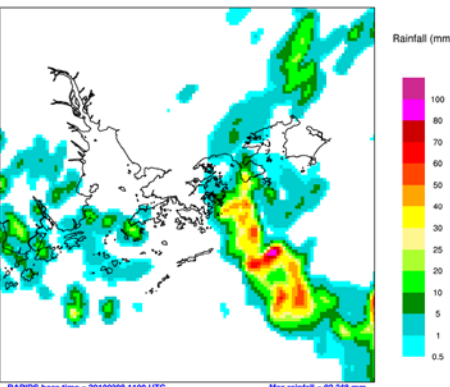
Blending
SWIRLS
+
NWP



RAPIDS base time = 20100908 1630 UTC

2km-NHM base time = 20100908 0900 UTC

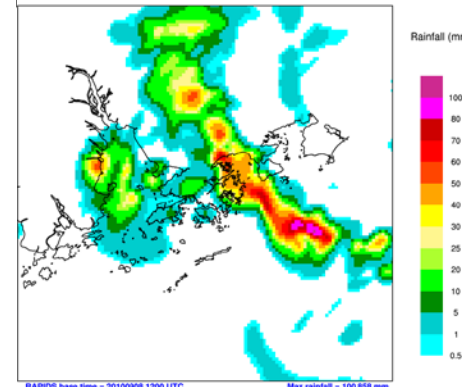
Max rainfall = 83.21 mm



RAPIDS base time = 20100908 1100 UTC

2km-NHM base time = 20100908 0900 UTC

Max rainfall = 92.24 mm



RAPIDS base time = 20100908 1200 UTC

2km-NHM base time = 20100908 1000 UTC

Max rainfall = 100.85 mm

Summary

- Radar data in SWIRLS nowcasting system
 - Quantitative precipitation estimates
 - Quantitative precipitation nowcast (0-9 hr)
 - Severe weather parameters (lightning, hail, downburst)
- Use of radar data in convection-permitting NWP model (RAPIDS-NHM)
 - Improve very-short-range forecast
- Blending of nowcast and NWP rainfall (RAPIDS)

Thank you very much



Dr. Tin
HKO's Mascot

