RSMC for Nowcasting & SWIRLS Nowcasting System

WC Woo, Hong Kong Observatory

Typhoon Committee Roving Seminar 2019

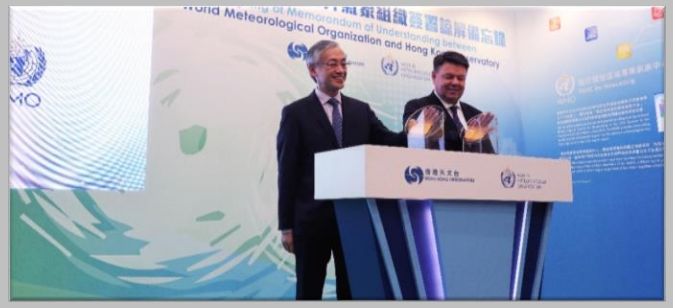
Beijing, China

11 November 2019

RSMC for Nowcasting

Protecting Lives and Properties with Science and Technology

- The Hong Kong Observatory (HKO) was designated as an RSMC for Nowcasting for the Asian region at the 70th Session of the Executive Council of the WMO in June, 2018.



WMO

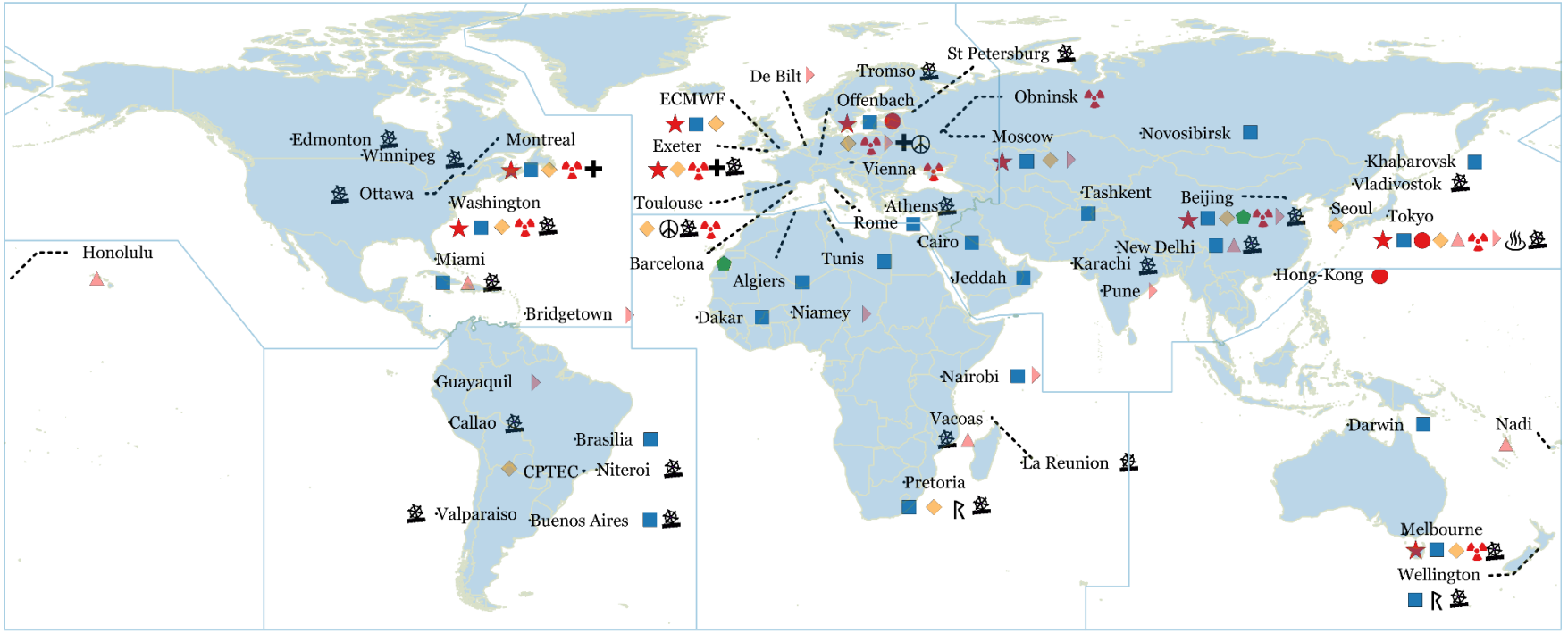
臨近預報區域專業氣象中心
RSMC for Nowcasting

臨近預報區域專業氣象中心
RSMC for Nowcasting

香港天文台
HONG KONG OBSERVATORY

WMO Designated Global Data-processing and Forecasting System Centres

Updated on 30 August 2018



Legend

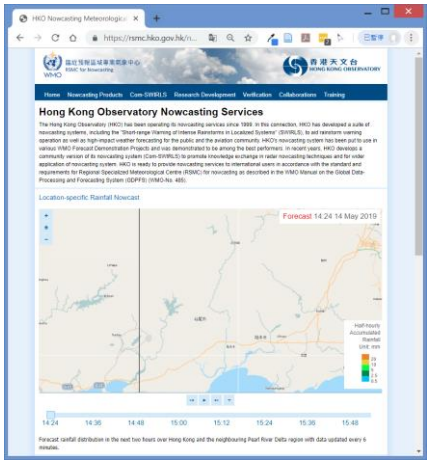
- World Meteorological Centres* (9)
- Global Producing Centres for Long-Range Forecasts (13)
- Global Producing Centres for Annual to Decadal Climate Prediction (3)
- RSMCs Geographic (25)
- RSMC Nowcasting (3)
- RSMCs TC (6)
- RSMCs Sand/Dust (2)
- Regional Climate Centres (11)
- RSMCs Nuclear Emergency Response** (10)
- RSMCs Non-Nuclear Emergency Response** (2)
- RSMCs Volcano Watch Services for International Air Navigation (1)
- RSMCs Severe Weather Forecasting (2)
- RSMCs Marine Meteorological Services (24)

* World Meteorological Centres are also Global Producing Centres for a) Deterministic Numerical Weather Prediction, b) Ensemble Numerical Weather Prediction, and c) Long-Range Forecasts.

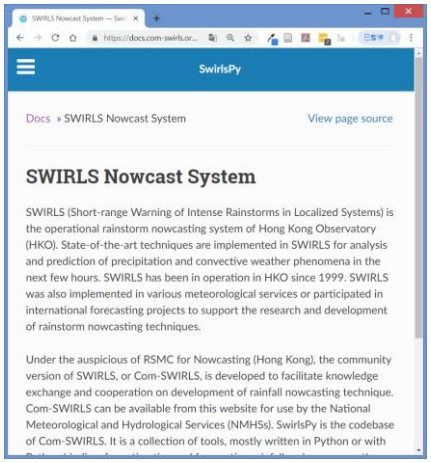
** RSMC for nuclear and non-nuclear emergency response have Atmospheric Transport and Dispersion Modelling (ATDM) capabilities.

Services

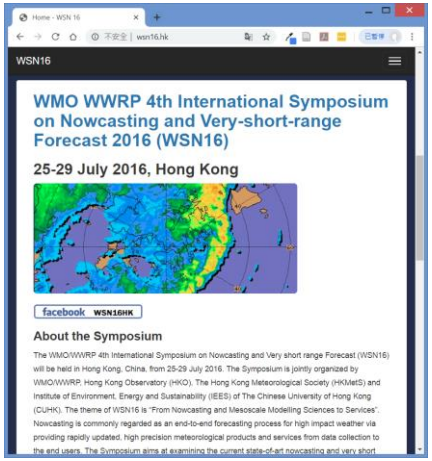
臨近預報區域專業氣象中心
RSMC for Nowcasting



RSMC Nowcast Products
RSMC Website



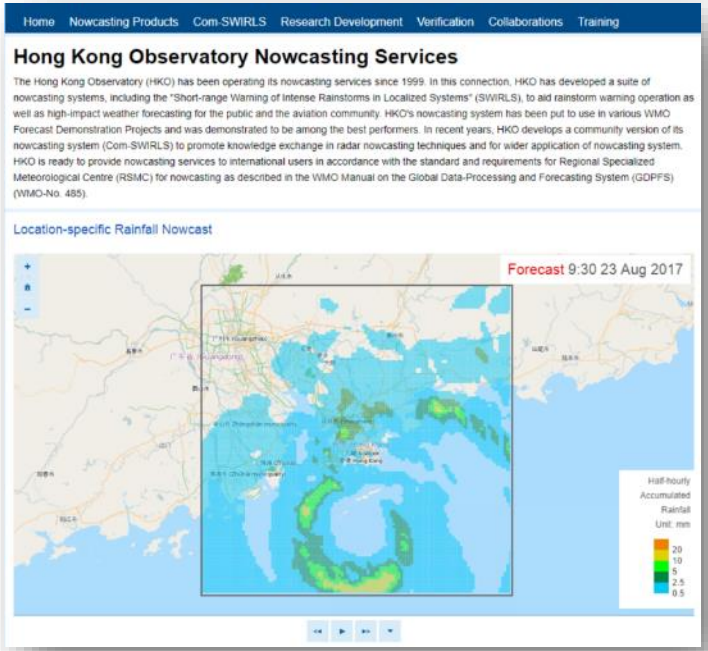
Builds Nowcast Systems
Community SWIRLS



Training and Exchange
Seminar / Workshop

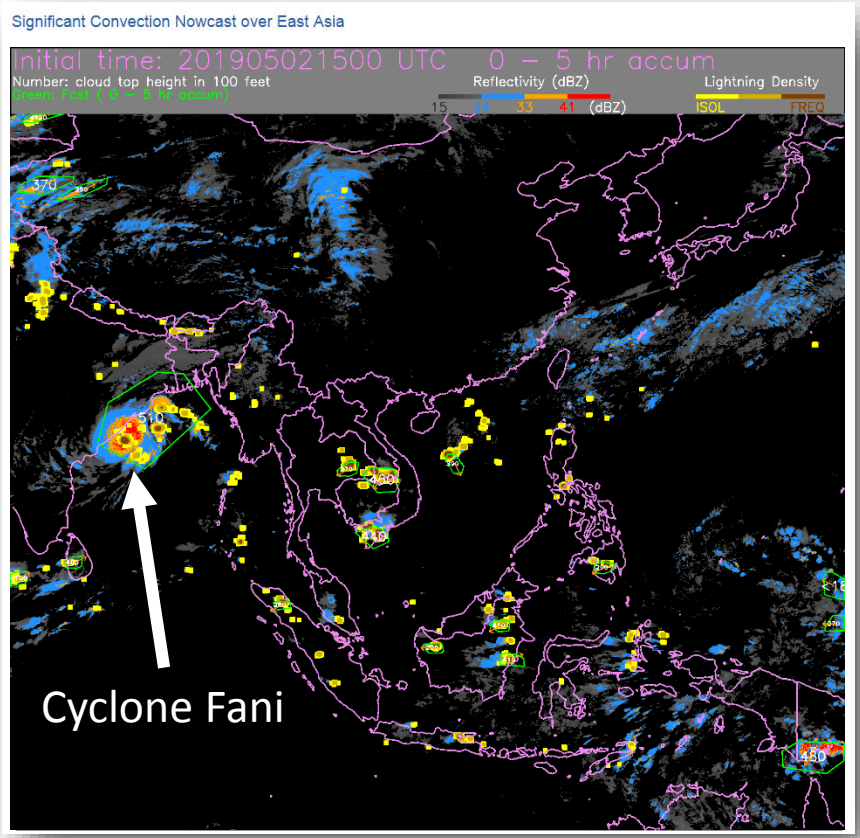
RSMC Website

2-Hour Quantitative Precpitation Nowcast over Pearl River Delta



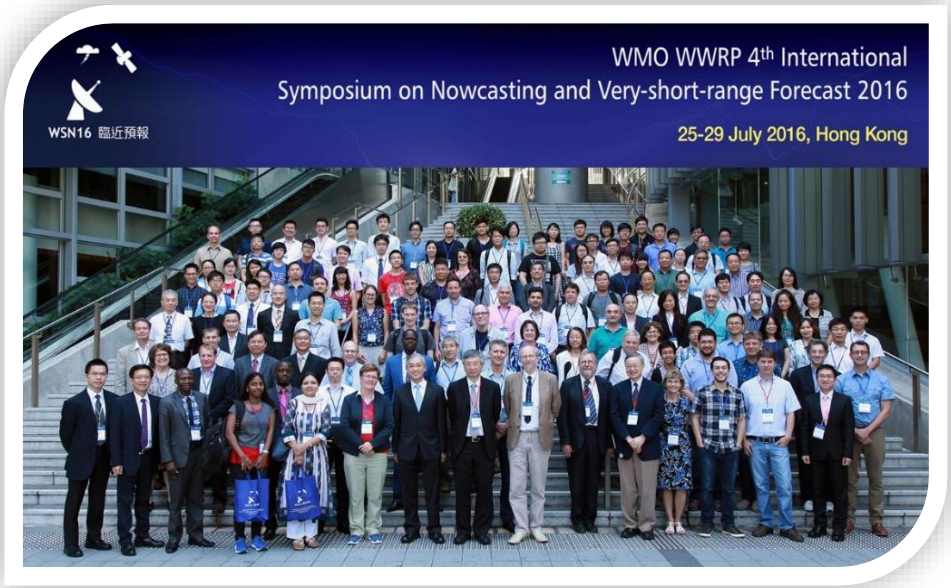
Super Typhoon Hato

Thunderstorm and Lightning in Asia
In the next 6 hours



Training Workshops

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

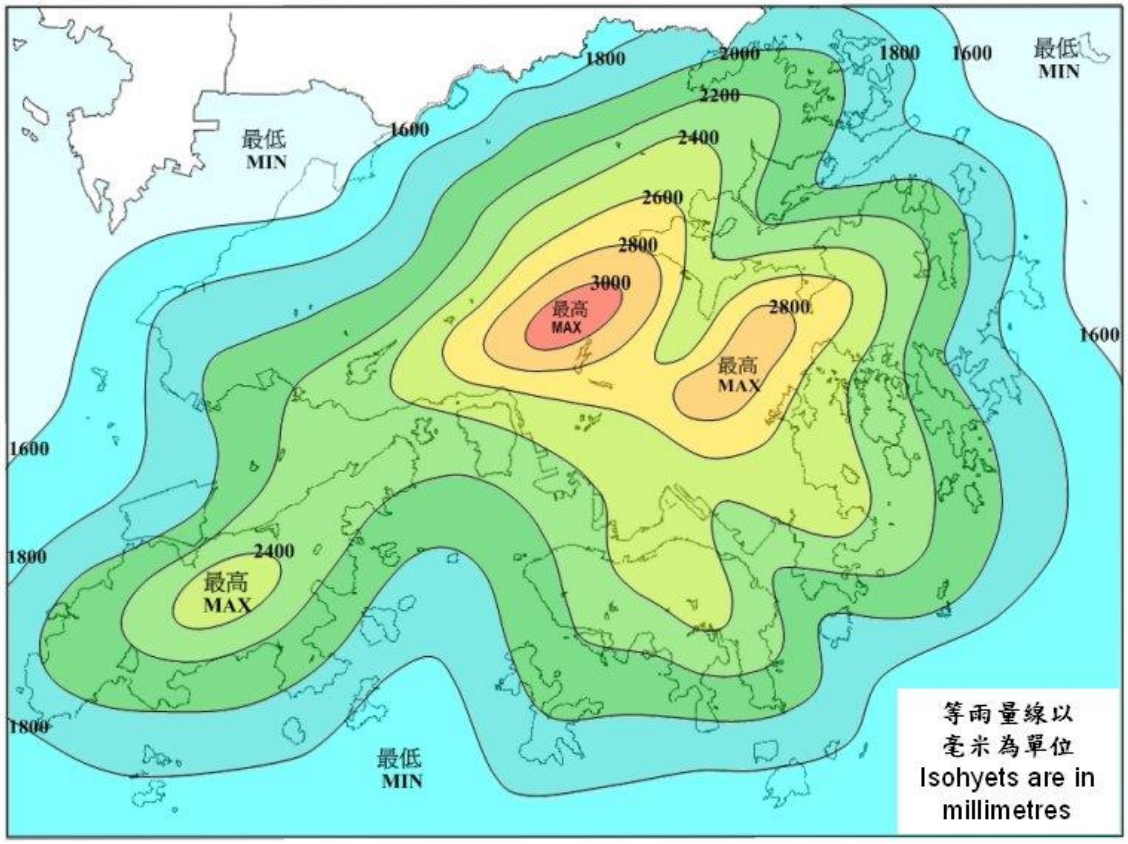


WMO VCP International Training Workshop on Rainfall Nowcast

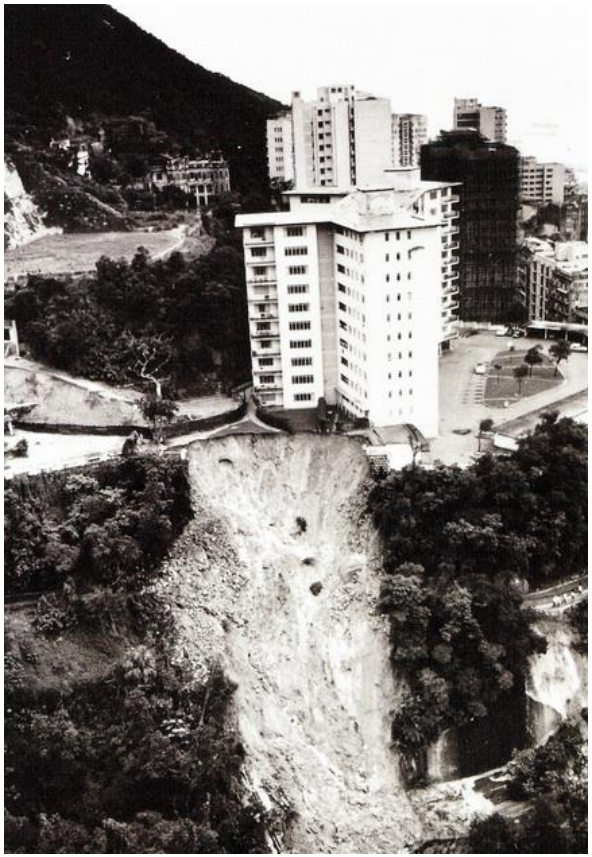
SWIRLS Nowcasting System

Climatological Distribution of Hong Kong Rainfall

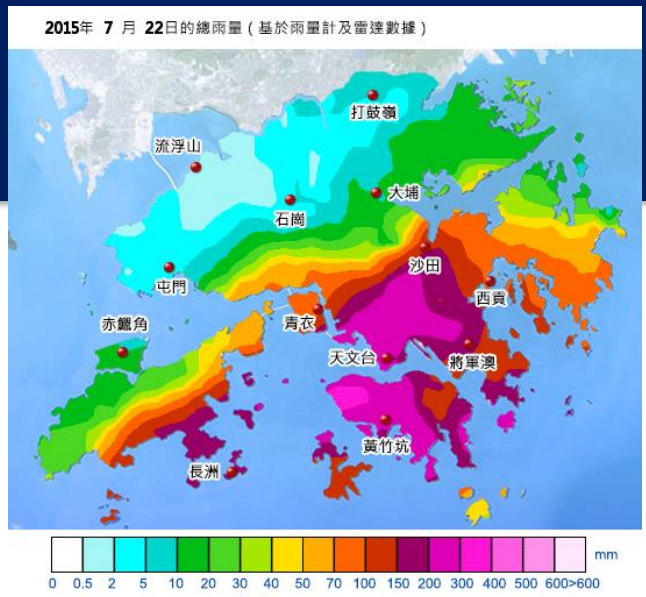
- Rainstorm and Significant Convective Processes
  - Summer Monsoon
  - Trough of low pressure
  - Tropical cyclone
- Local terrain effects

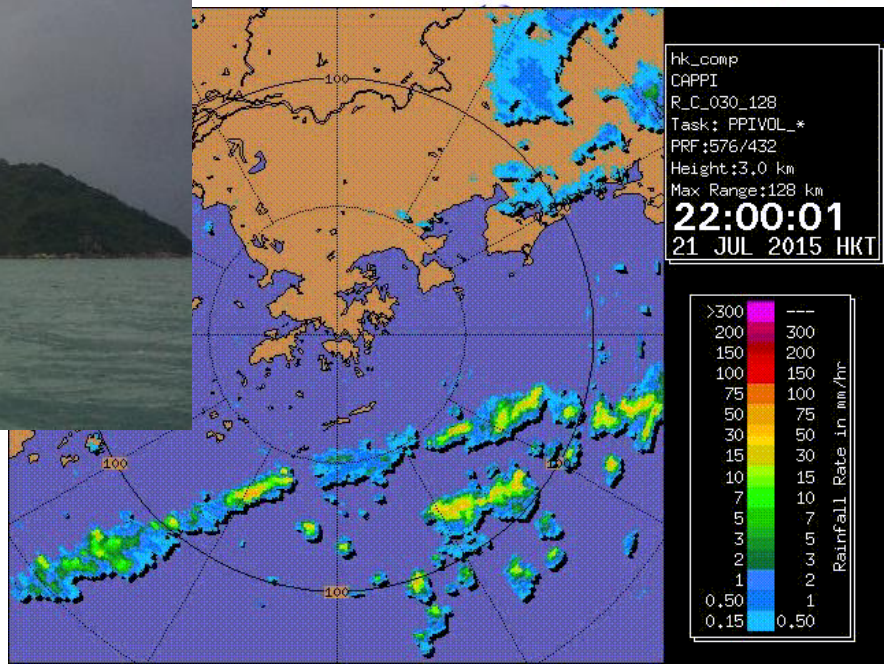


Rainstorms

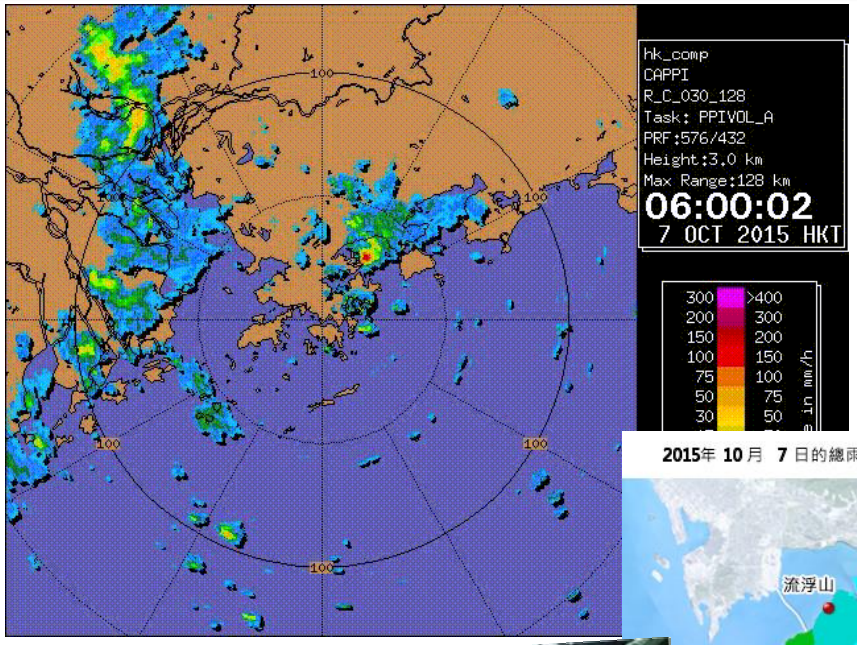


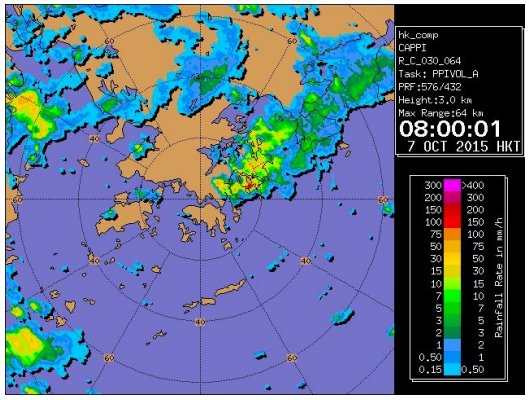
Sticky Downpours and Waterspout on 22 July 2015

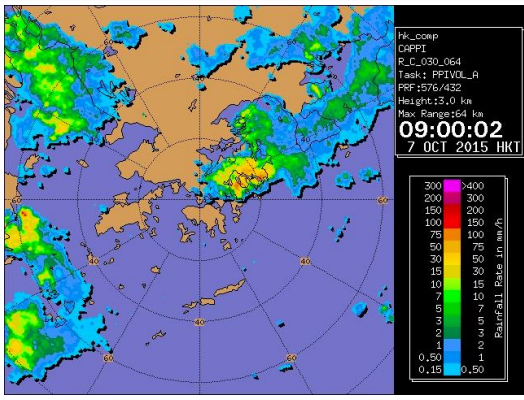


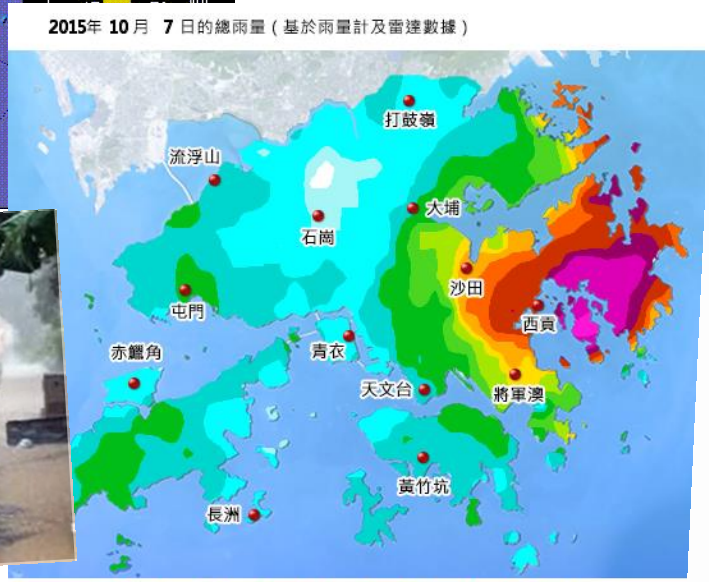


Localized Heavy Rain on 7 Oct 2015









WMO

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Warning Signals on Rainstorm, Flooding and Landslide

- Amber Rainstorm Signal

Heavy rain has fallen or is expected to fall generally over Hong Kong, exceeding 30 mm in an hour, and is likely to continue.

Thunderstorm Warning

- Red Rainstorm Signal

Heavy rain has fallen or is expected to fall generally over Hong Kong, exceeding 50 mm in an hour, and is likely to continue.

Landslip Warning

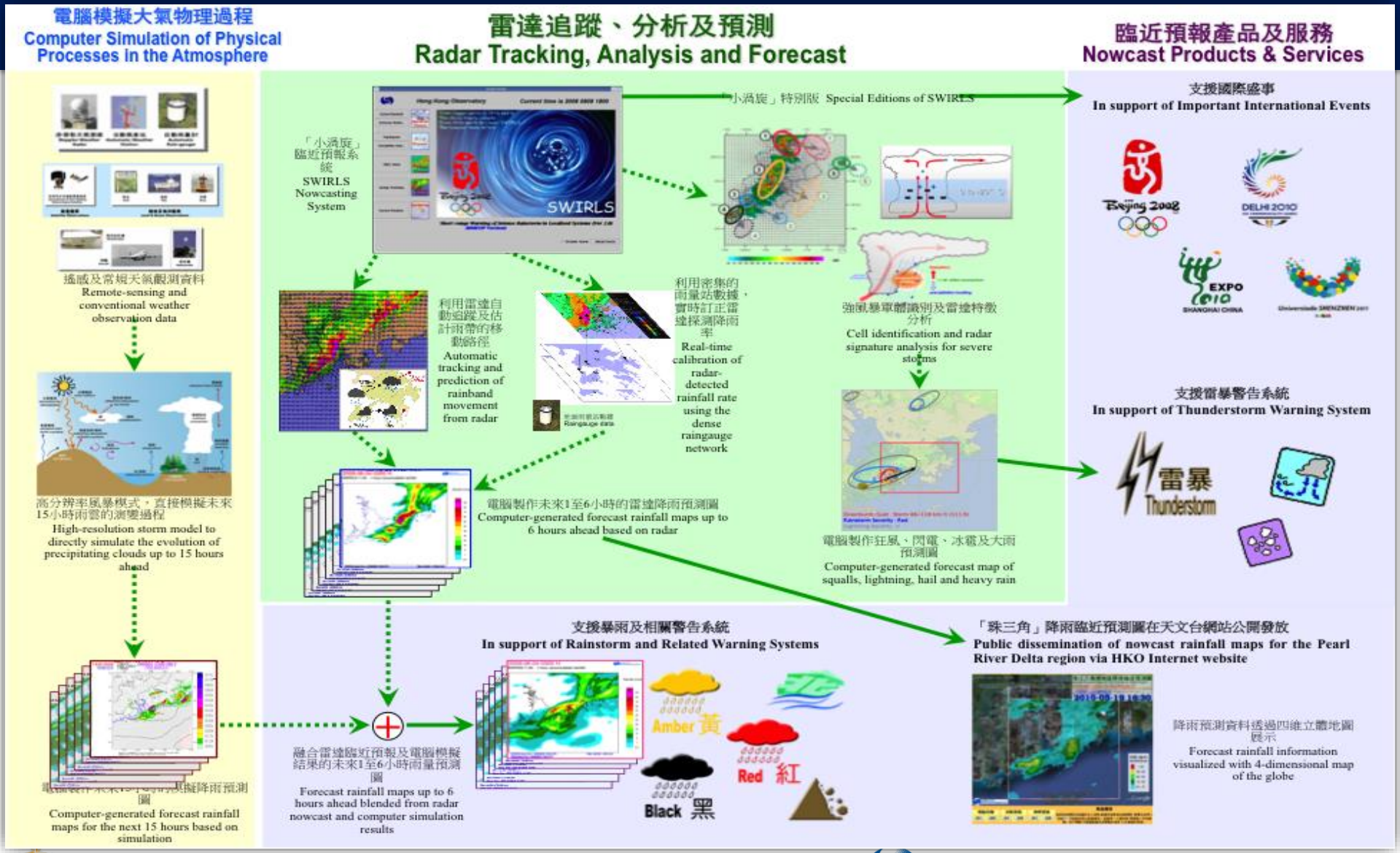
- Black Rainstorm Signal

Heavy rain has fallen or is expected to fall generally over Hong Kong, exceeding 70 mm in an hour, and is likely to continue.

Special Announcement on Flooding in the northern New Territories

SWIRLS –

Short-range Warning of Intense Rainstorm in Localized Systems



Main Features of SWIRLS

- Quantitative Precipitation Estimation (QPE)
  - radar-based, raingauge-based or blended
- Retrieval of echo motion
  - tracking by optical flow
  - tracking by maximum correlation (TREC)
  - object-oriented tracking of storm motion
- Quantitative Precipitation Forecast (QPF) using semi-Lagrangian advection scheme to extrapolate radar reflectivity up to 6 or 9 hours
- Computation of gridded precipitation nowcast and locations of storm objects of convective wind gust, lightning and hail
- Probabilistic QPF and blending with convection permitting NWP model
- Nowcasting products for forecasters, government users, and public

Doppler Weather Radars

Tai Mo Shan
S band
(968 aMSL)

~ 40km

Brothers Point TDWR
C band
(80 aMSL)

Tai Lam Chung TDWR
C band
(59 aMSL)

HKIA

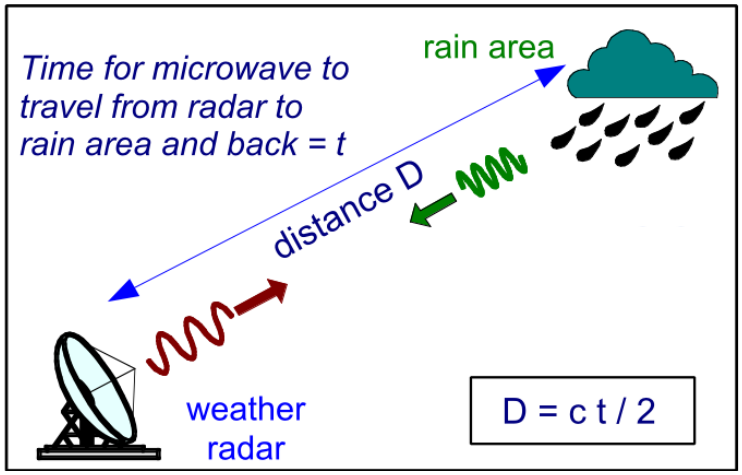
HKO Hq

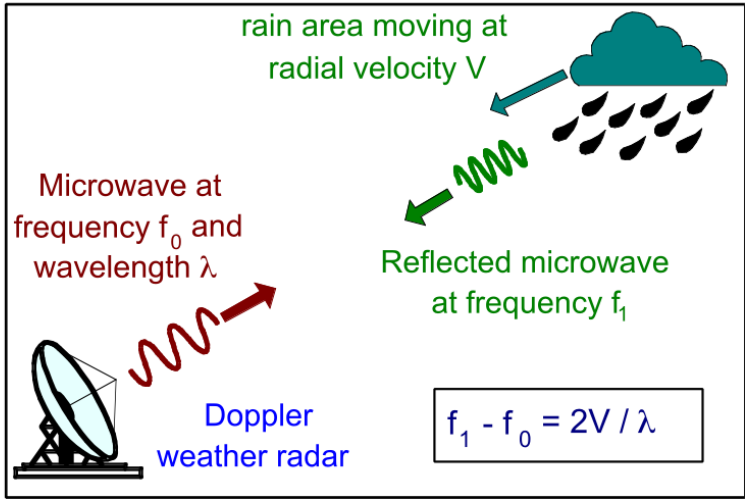
Tate's Cairn
S band
(583 aMSL)

Siu Ho Wan
Dual-Pol X band
(32 aMSL)

~ 60km

Rain Drop, Reflectivity and Doppler Velocity





Reflectivity factor (Z) measured by weather radar is the sixth moment of drop size distribution N(D) (D=drop diameter in mm):

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

Rain rate (R) is given by:

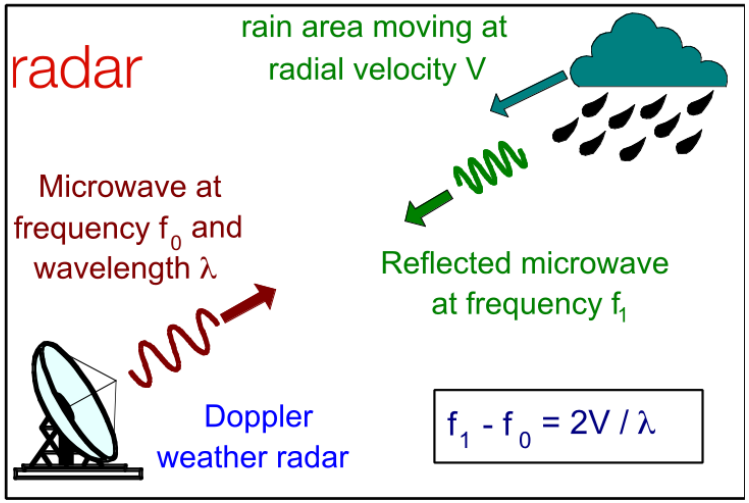
$$R = \frac{\pi}{6} \int_0^\infty N(D) D^3 V(D) dD$$

V(D) is the fall velocity of particles of size D

➔ *Z = Z (R, N(D))*

an empirical relationship on Z-R: $Z = a * R^b$

Radar Basic and Limits



Pulse repetition frequency (PRF)
= number of times a radar pulse sent out every second

Thus, the maximum range that a radar measure:
$\mathbf{R_{max}}$ = c/2 * (time between successive pulses)
$\mathbf{R_{max}}$ = c/2 * (1/PRF)

c = speed of light

Maximum unambiguous velocity (Nyquist velocity / Nyquist interval)

$\mathbf{V_{max}}$ = lambda * PRF / 4 (lambda = wavelength of radar signal)

Therefore: $\mathbf{R_{max}} * \mathbf{V_{max}}$ = c * lambda / 8

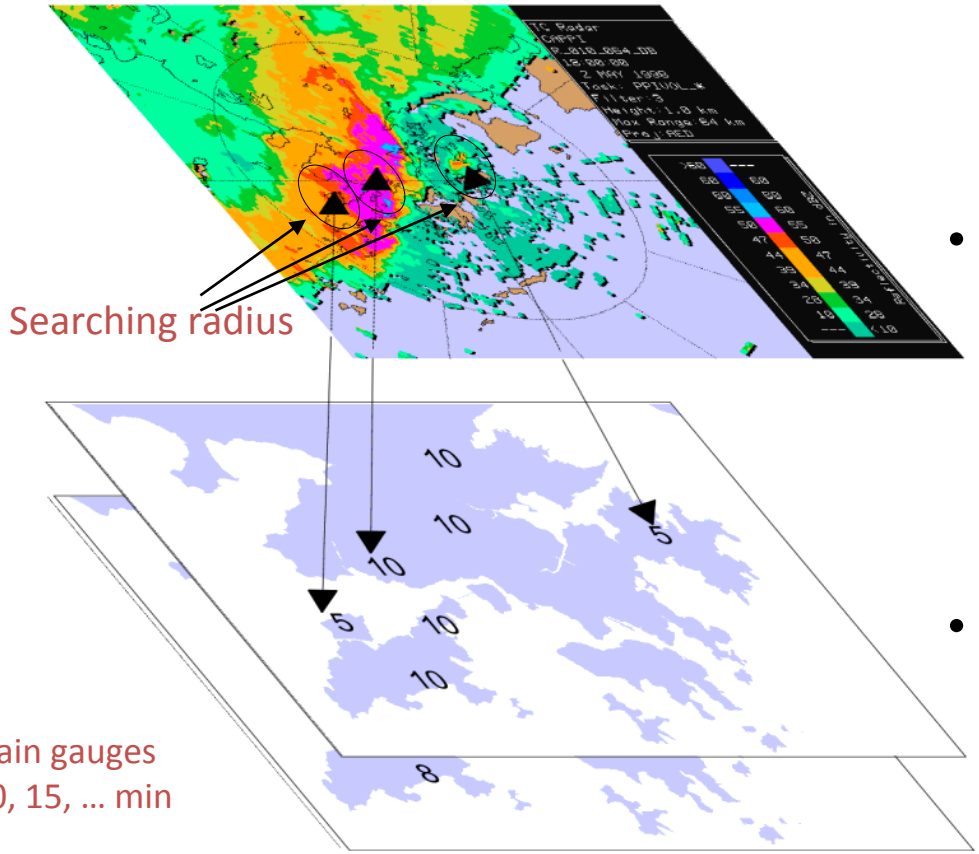
A Doppler Radar dilemma:
Choose PRF to attain a larger unambiguous range leading to a smaller unambiguous velocity

Type of radars for meteorological applications

Frequency	Band	Wavelength	Applications
400 - 900 MHz	UHF	0.3 - 0.7 m	wind profiler
1 GHz	L-band	0.3 m	boundary layer wind profiler
2-4 GHz	S-band	7-15 cm	long range precipitation radar
4-8 GHz	C-band	4-7 cm	long range precipitation radar
8-16 GHz	X-band	2-4 cm	precipitation radar
16-20 GHz	Ku-band	1-2 cm	precipitation / cloud radar
35 Hz	Ka-band	8.5 mm	precipitation / cloud radar
90-100 GHz	W-band	3 mm	cloud radars

QPE in SWIRLS - Basics

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



N=150 rain gauges
R: 05, 10, 15, … min

- converting reflectivity to rainfall rate

$$Z = aR^b$$

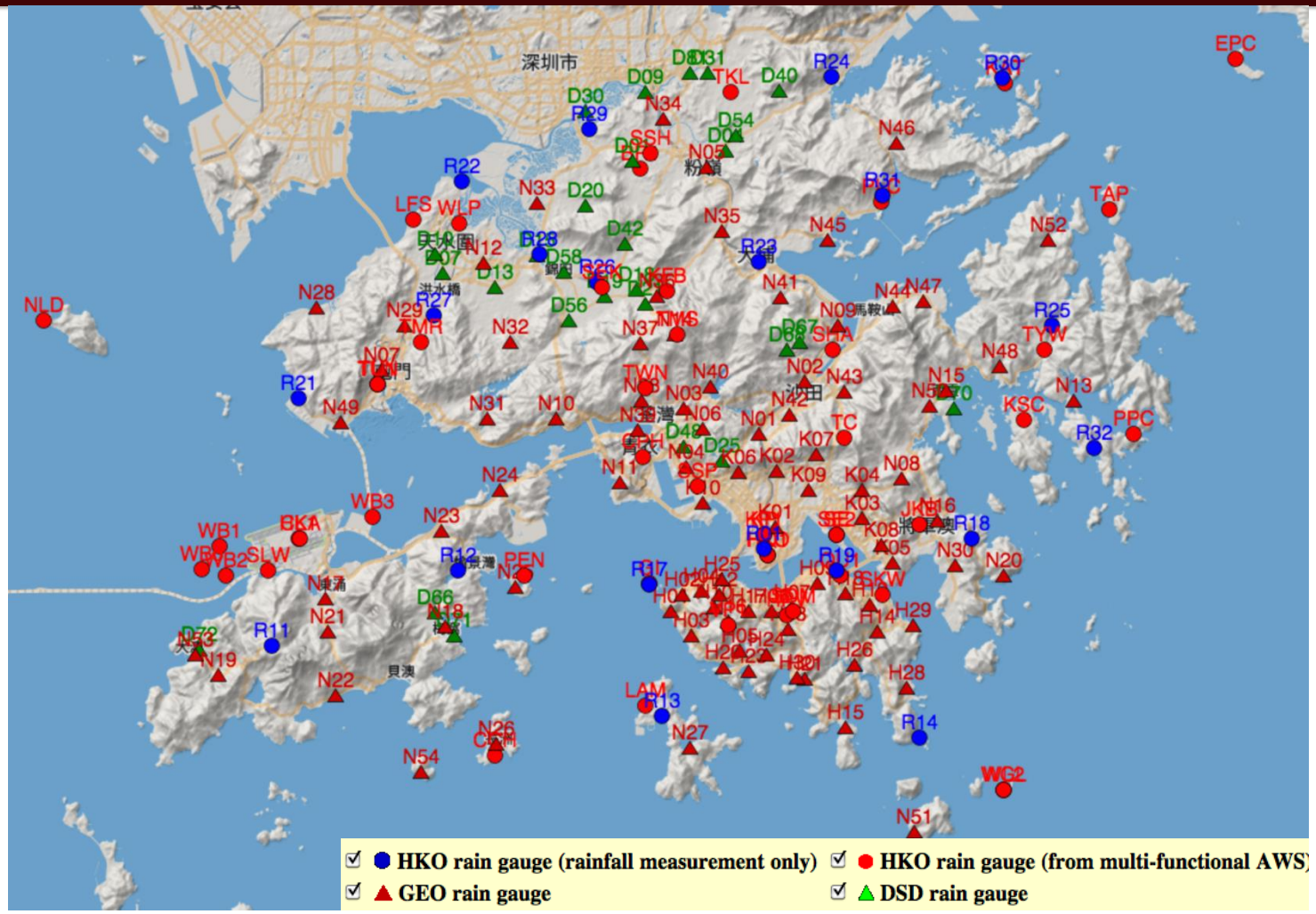
- seek (a, b) to minimize:

$$\sum_i^N (dBG_i - dBZ_i)^2$$

- where

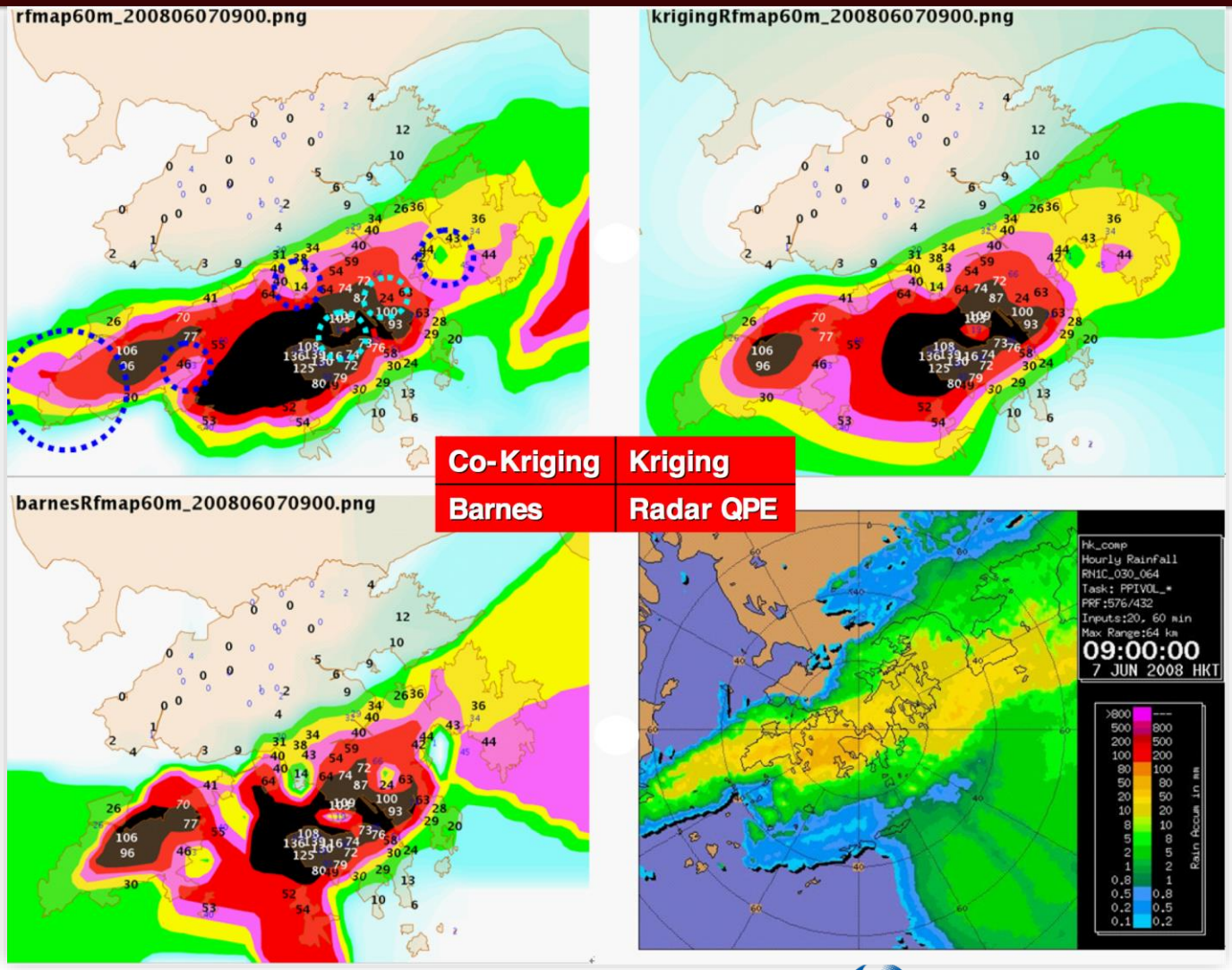
$$dBG_i = 10 \log R_i$$

Rain Gauge Network in Hong Kong



Total no. > 150, updated every 1 or 5 min, mean separation < ~ 3 km

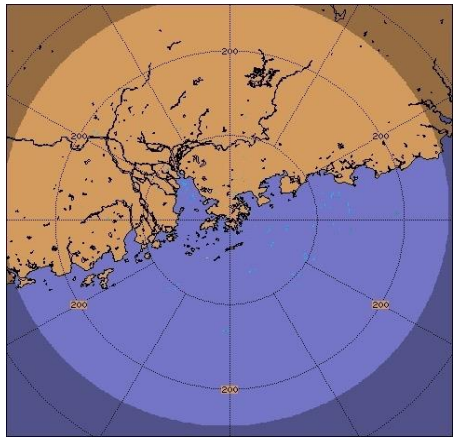
Different QPE Techniques in SWIRLS



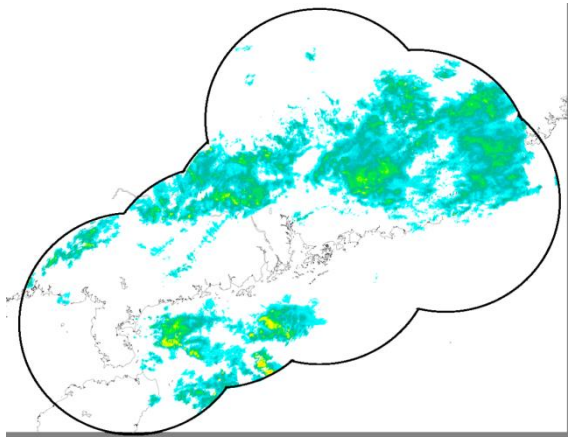
Multi-Sensor QPE in SWIRLS

512 km

512 km

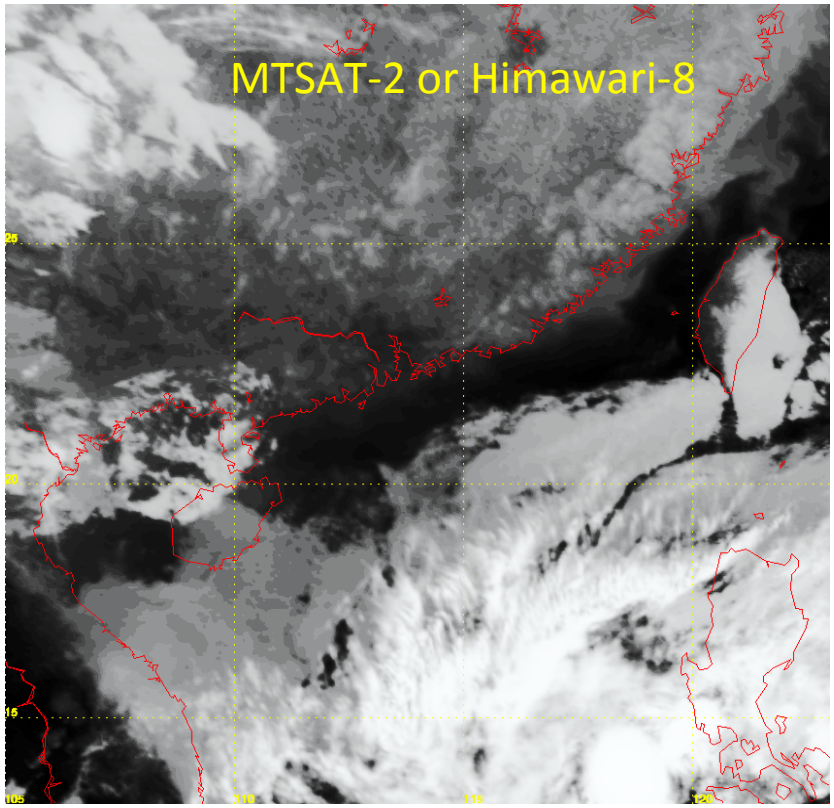


~ 900 km



~ 1100 km

~1800 km

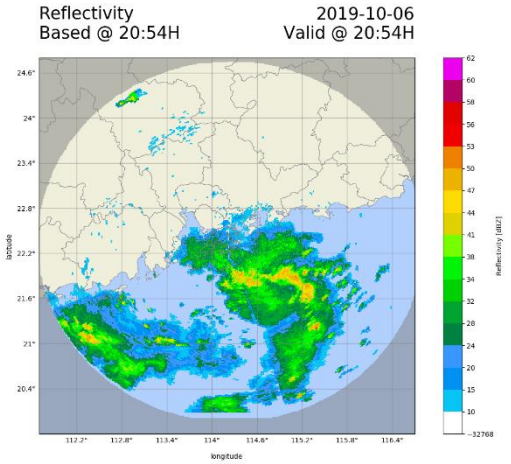


~ 1800 km

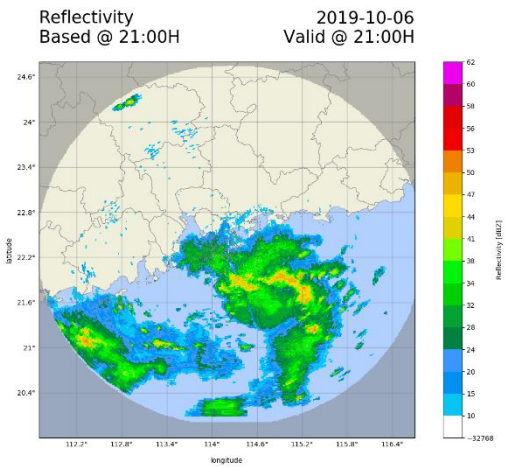
Retrieval of Echo Motion and Quantitative Precipitation Forecast (QPF)

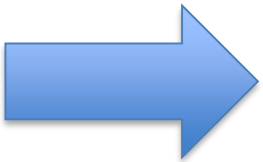
Calculate Motion Field

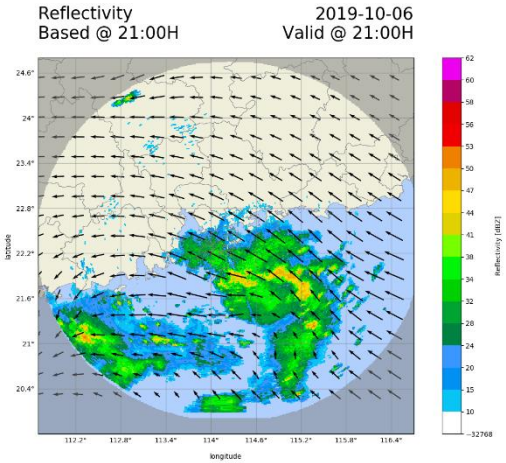
6 Minutes Earlier



Latest

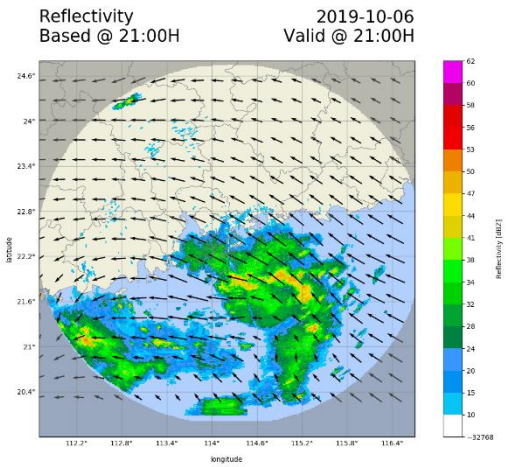






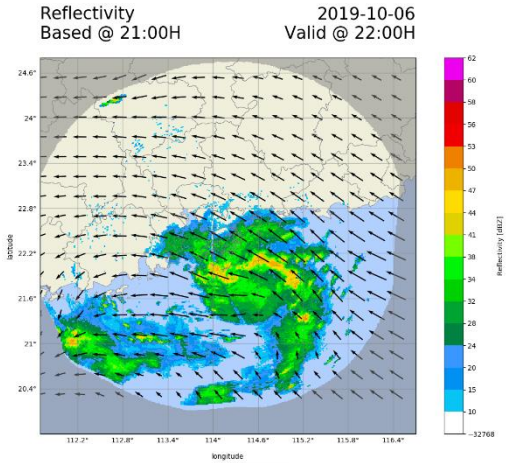
Motion Field

Extrapolate

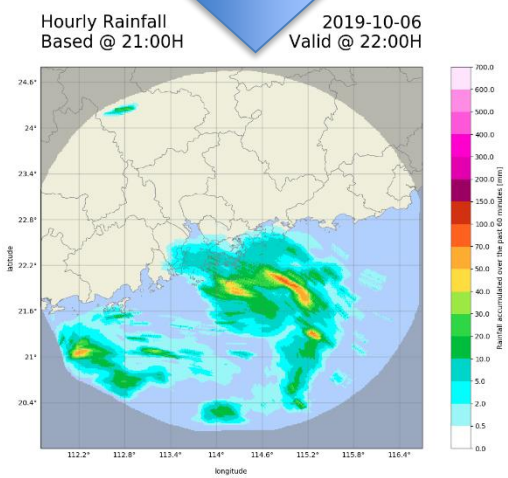


Observed Radar Reflectivity and Motion Field

GPU Computing



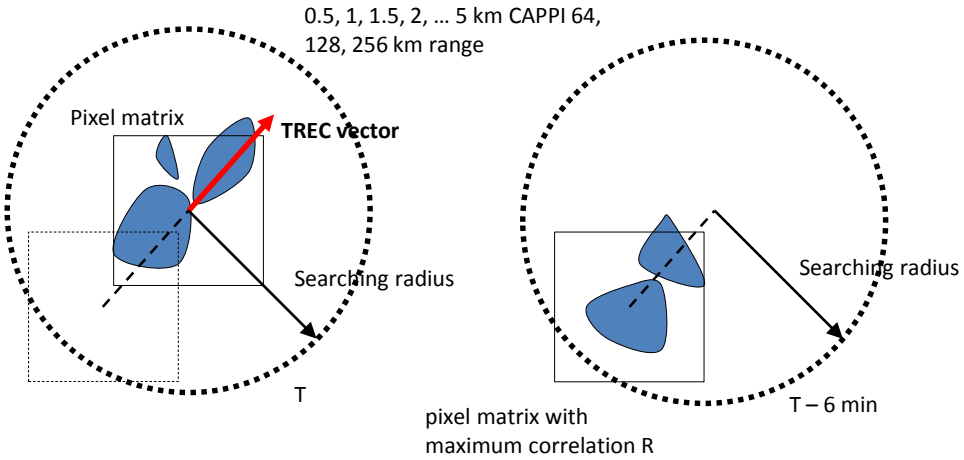
Forecast Radar Reflectivity



Forecast Rainfall

Echo Tracking Algorithms in SWIRLS

Maximum Correlation (TREC)



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

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

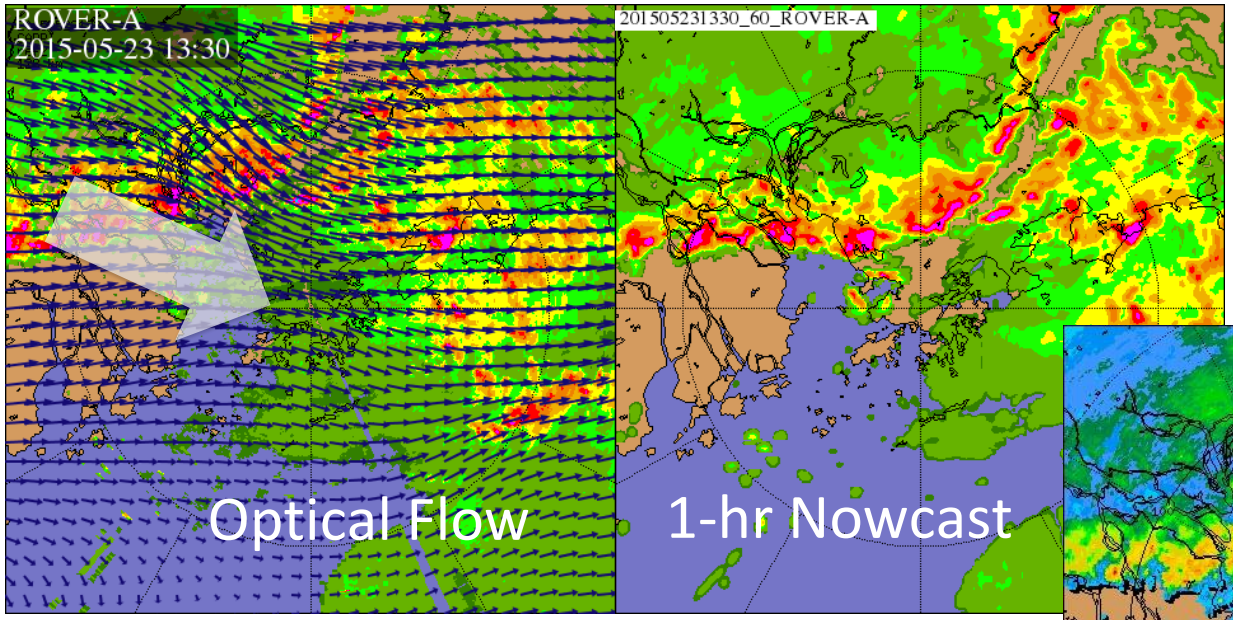
Optical Flow

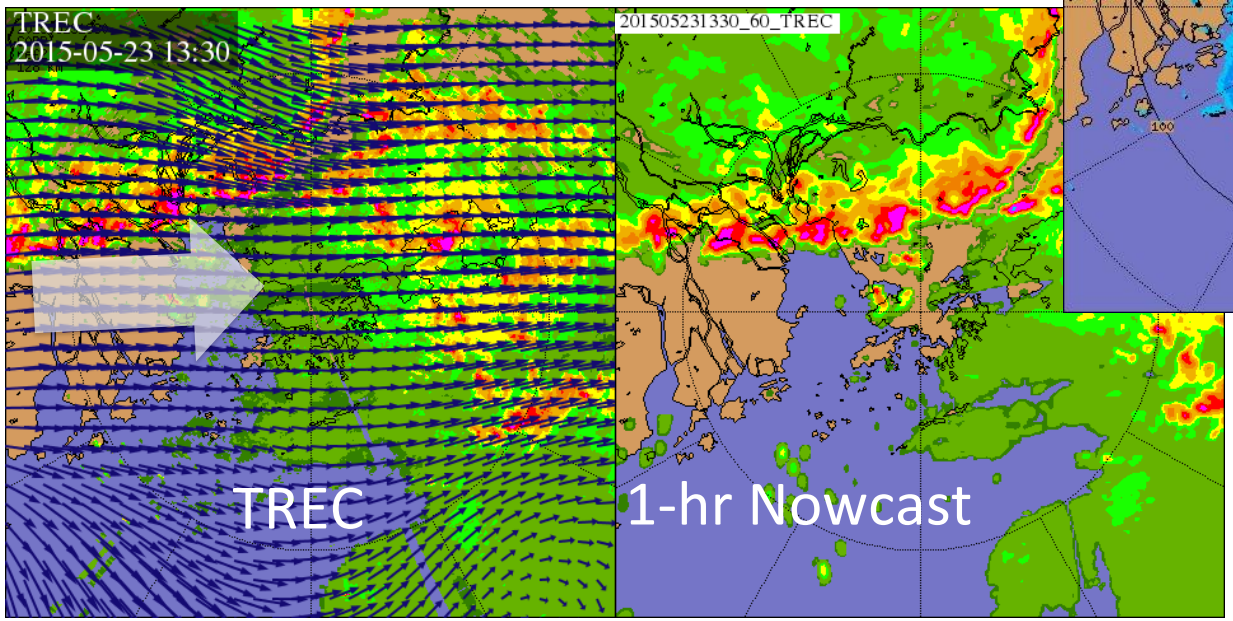
Given I(x,y,t) the image brightness at point (x,y) at time t and the brightness is constant when pattern moves, the echo motion components u(x,y) and v(x,y) can be retrieved via minimisation of the cost function J :

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

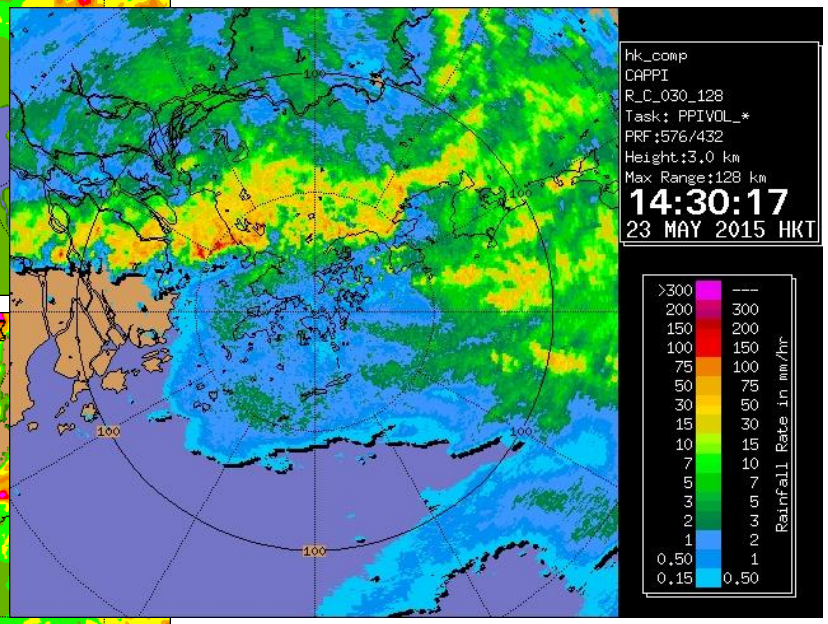
An integral approach, retrieval of echo motion from large scale to small scale

13:30 HKT 23 May 2015

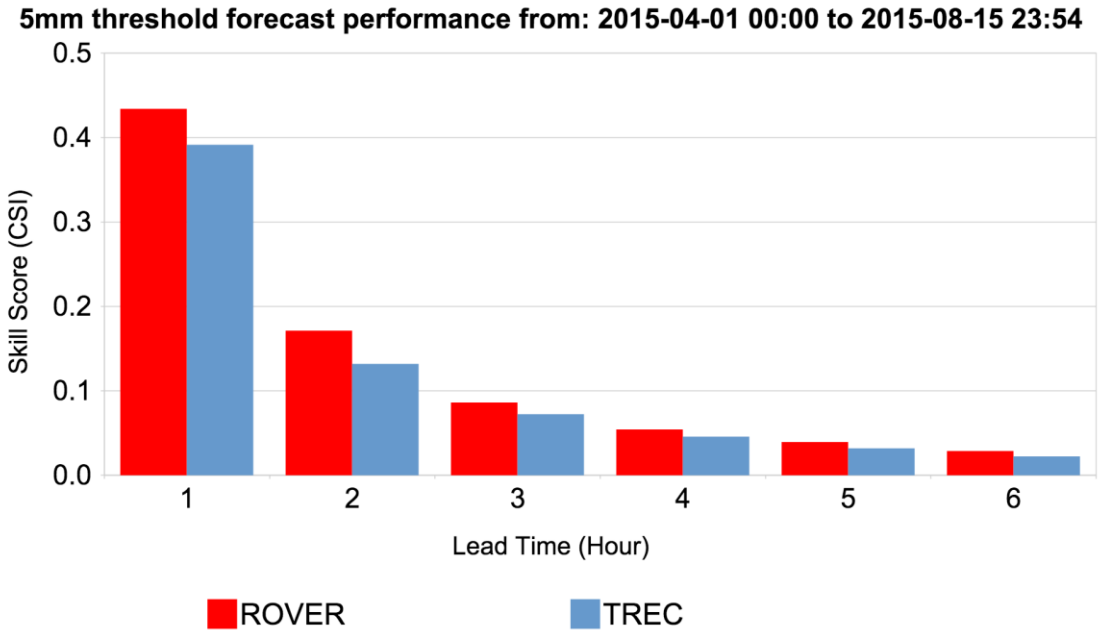




Actual at
14:30 HKT 23 May 2015



Effect of echo tracking on QPF verification (1 Apr - 15 Aug 2015)

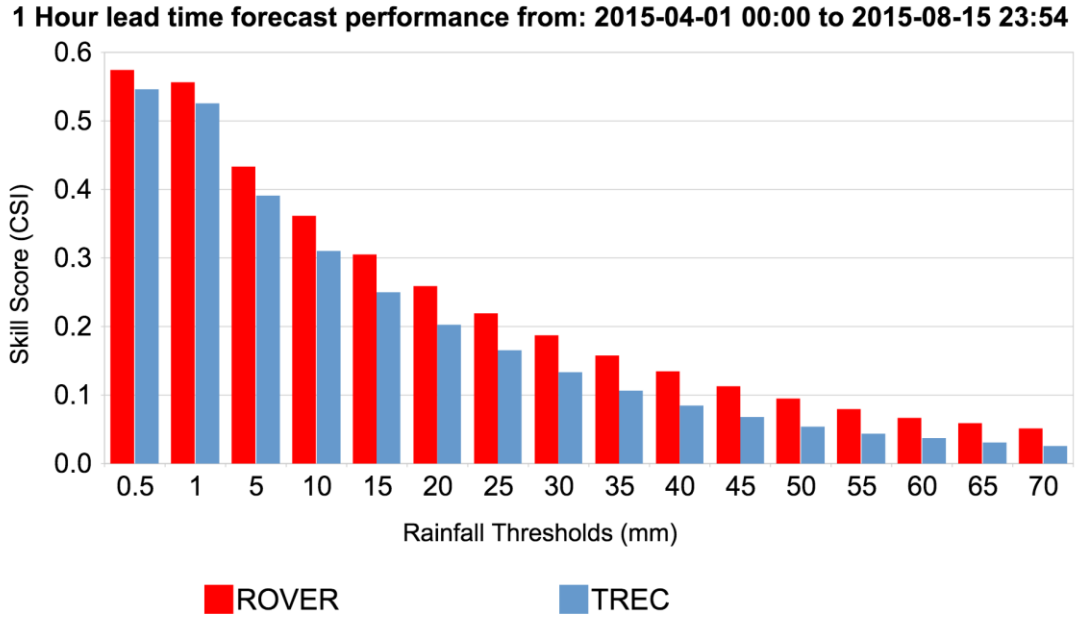


Verification method: grid based

CSI vs. lead time (T+1h to T+6h)

OPTICAL FLOW

TREC



CSI vs. T+1hour rainfall forecast at different thresholds (in mm)

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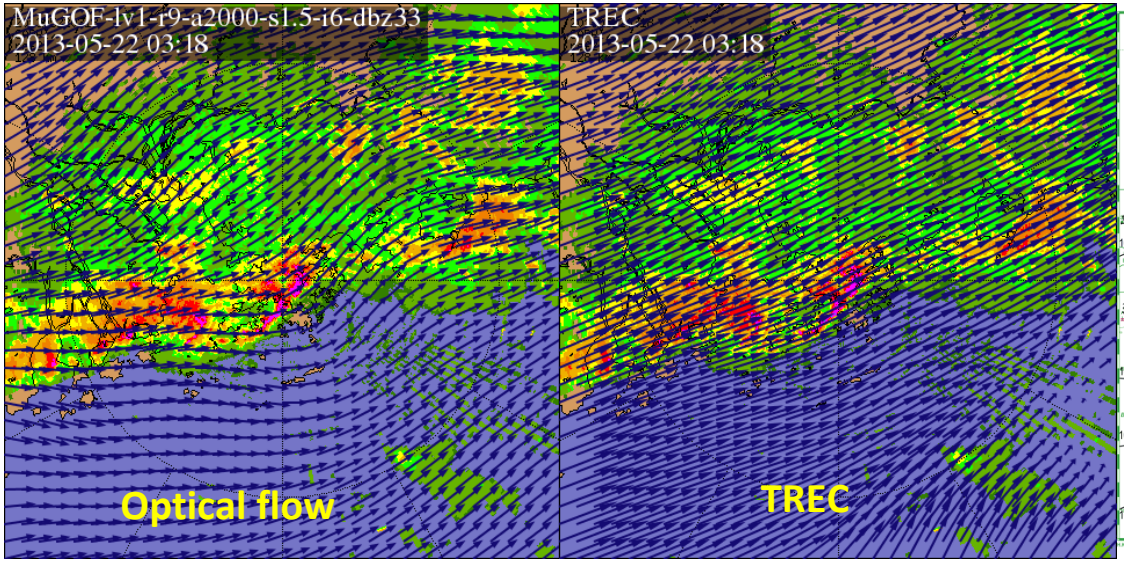
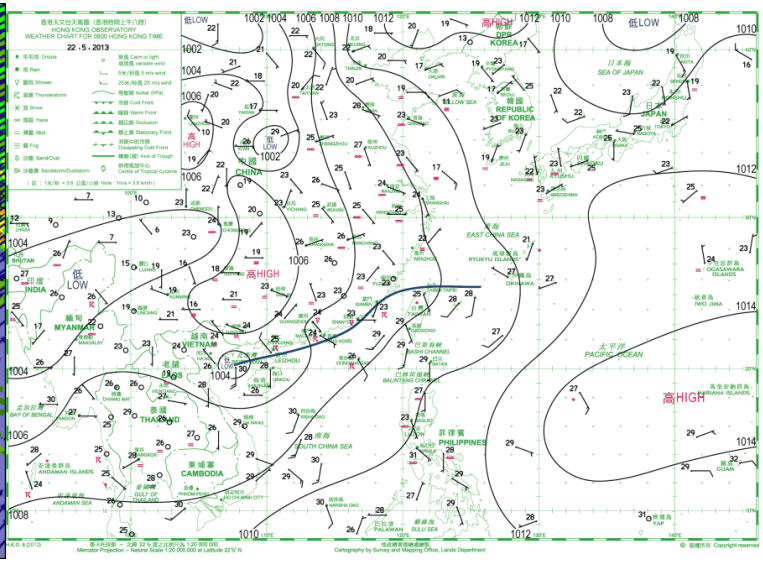
HONG KONG OBSERVATORY

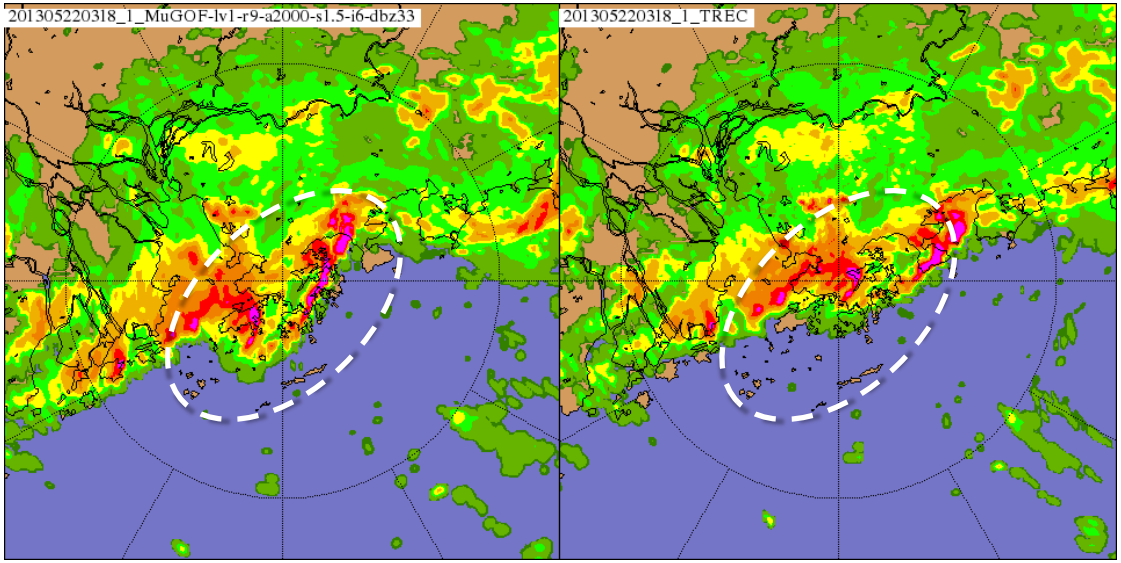
Black Rainstorm on 22 May 2013

Echo tracking at 03:18 HKT

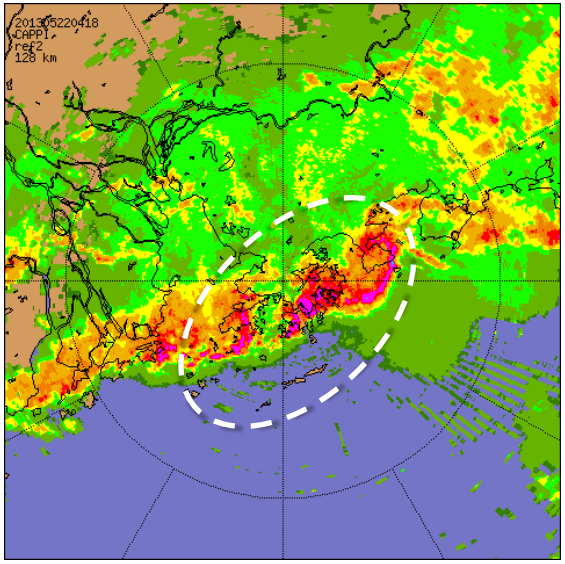




T+60min nowcast at 04:18 HKT

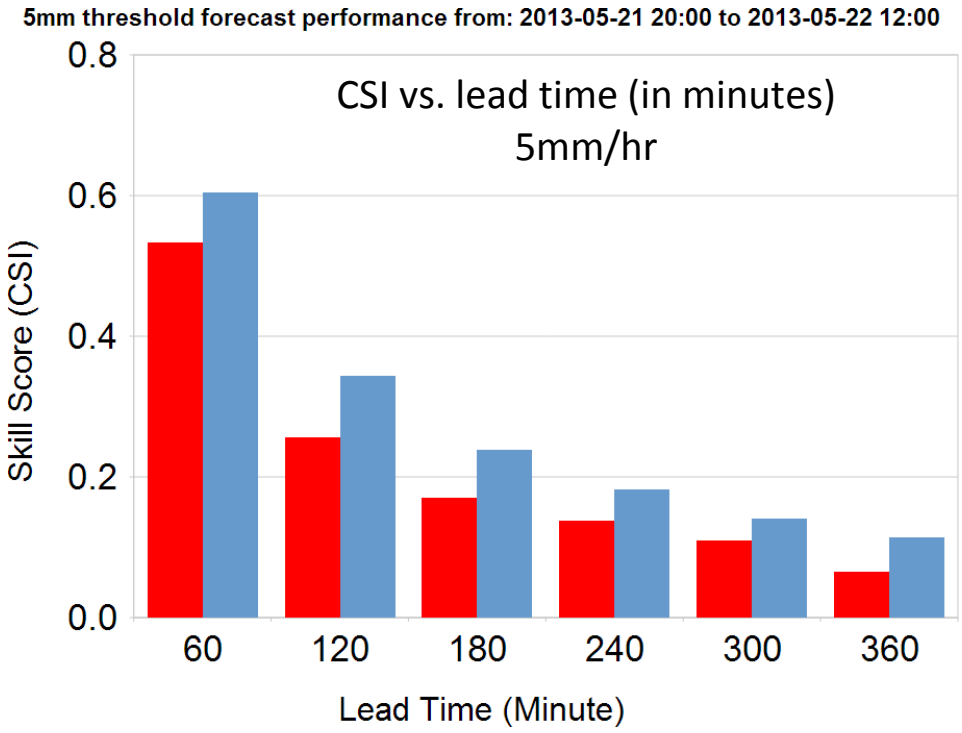


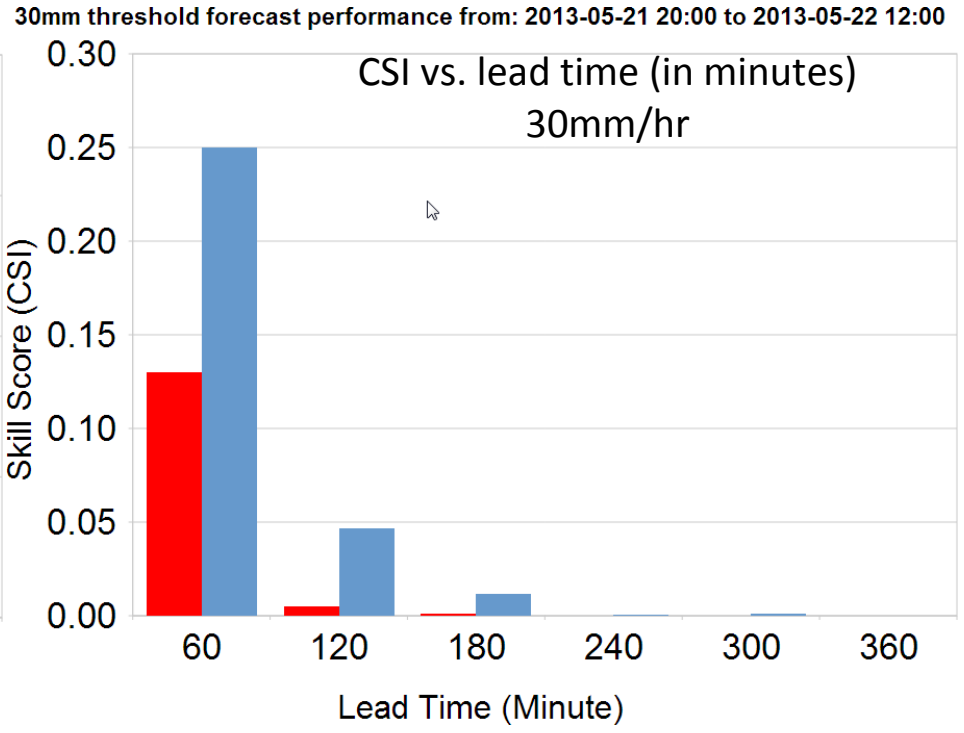
ACTUAL radar reflectivity at 04:18 HKT



Impact on QPF (CSI vs. lead time)

TREC Optical Flow

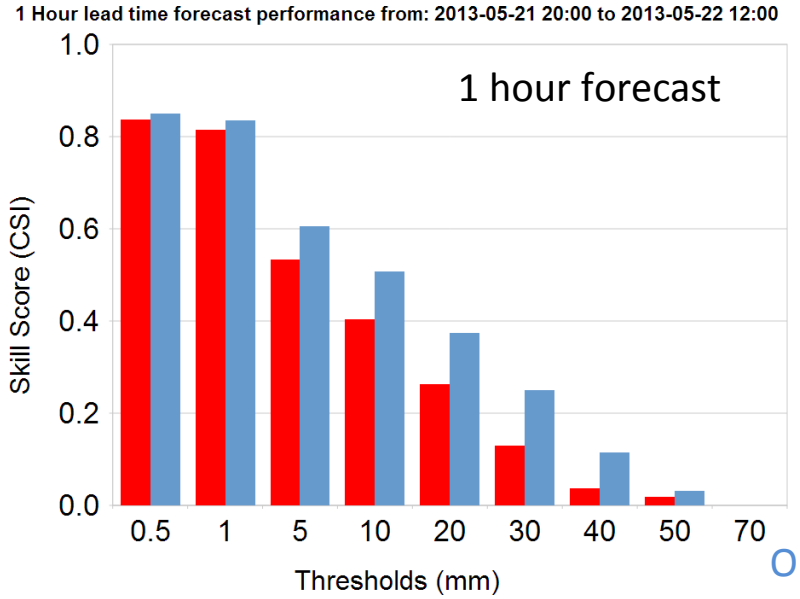


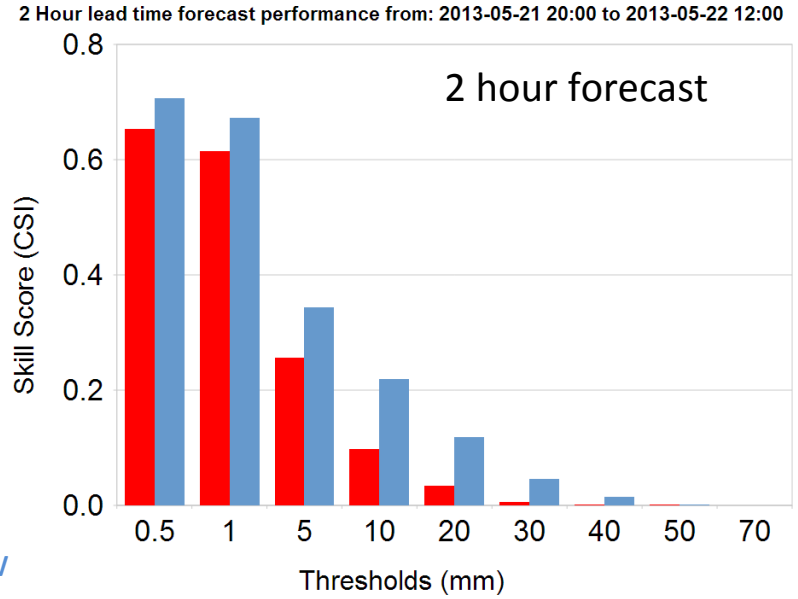


Verification method: grid based

(horizontal resolution at 2 km) over HK and PRD

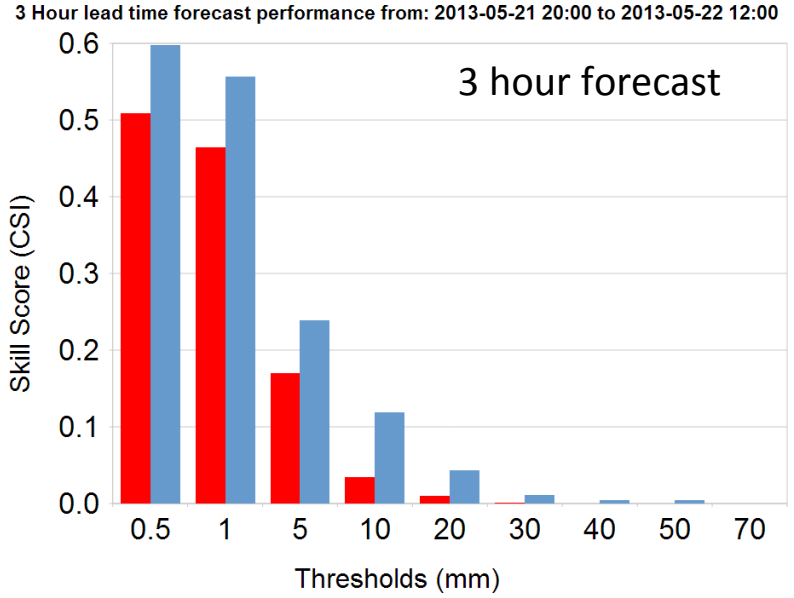
Impact on QPF (CSI vs. rainfall intensity)

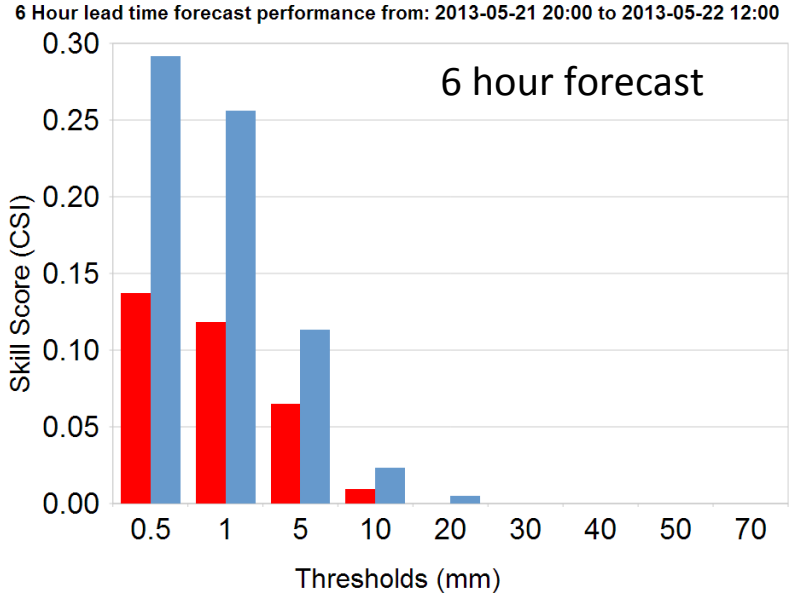




TREC

Optical Flow

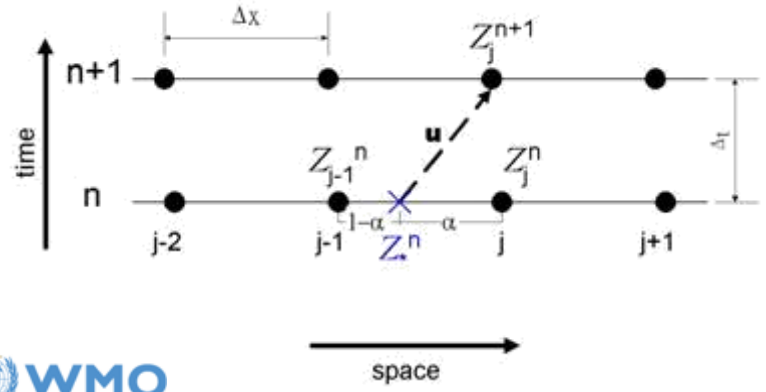


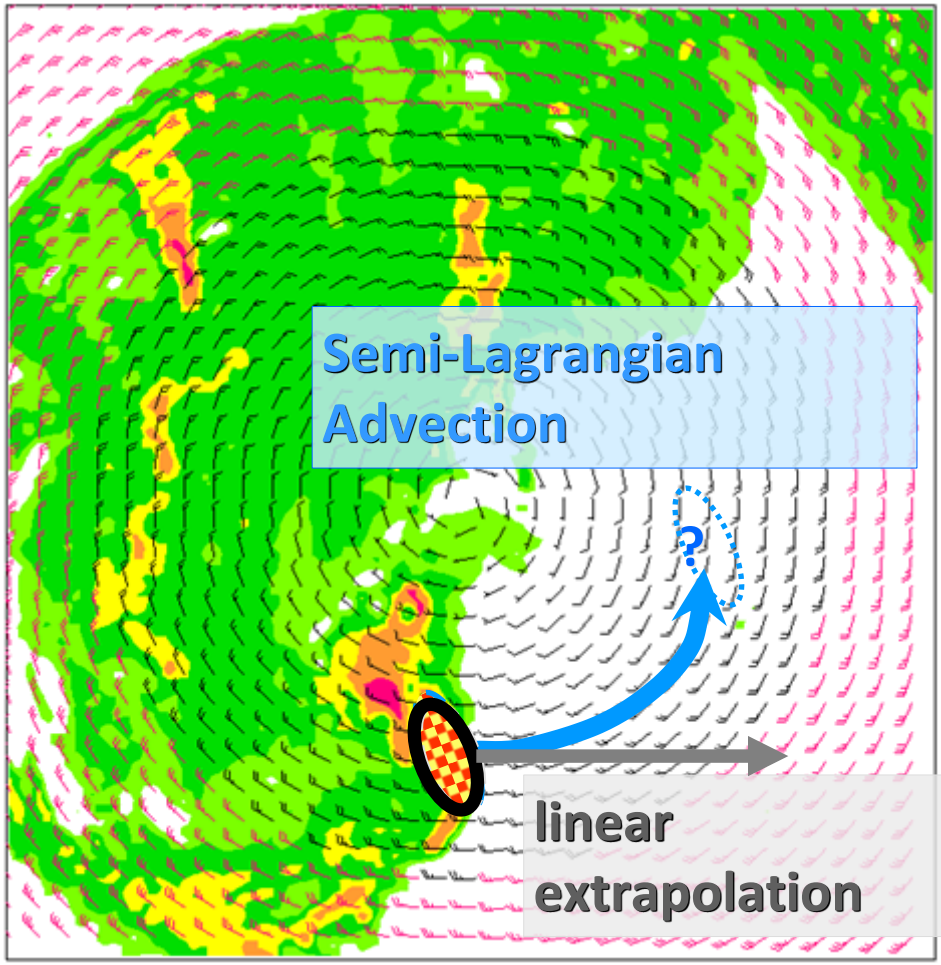


SWIRLS Semi Lagrangian Advection (SLA)

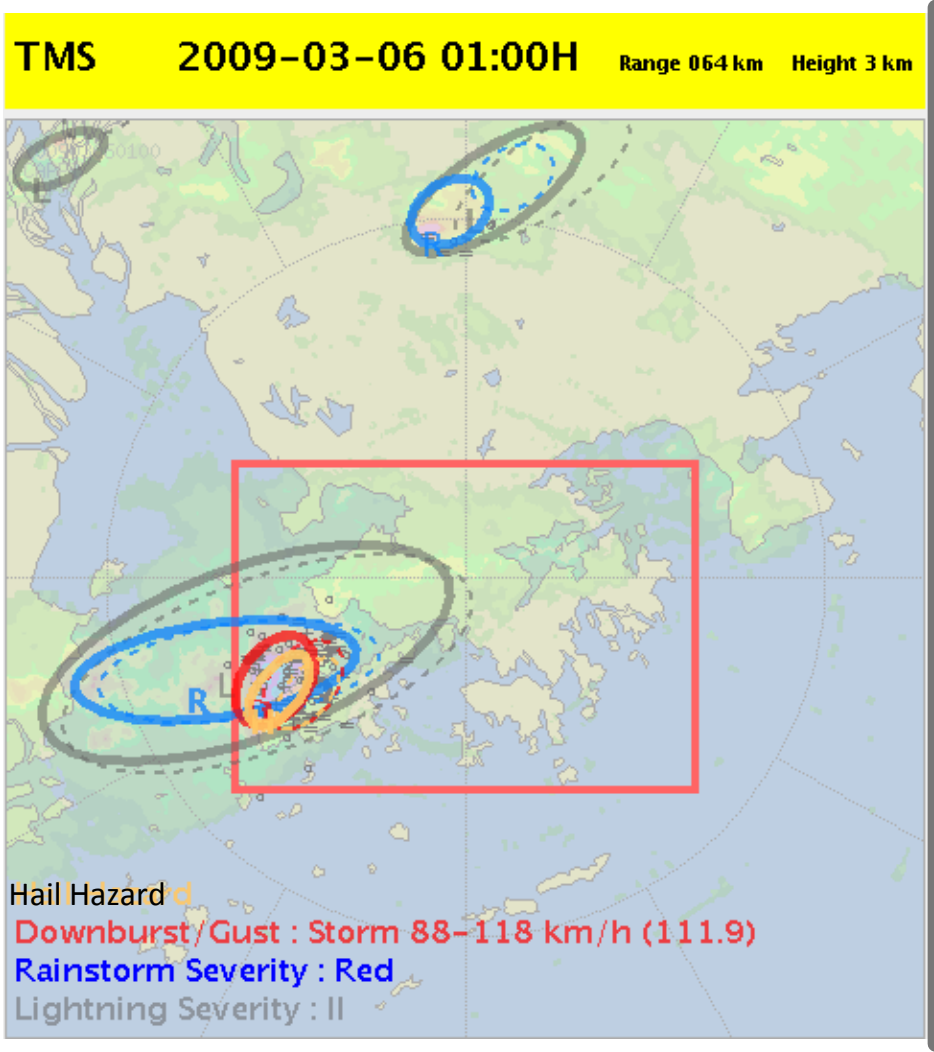
$$\frac{dZ}{dt} = \frac{\partial Z}{\partial t} + \mathbf{u}\frac{\partial Z}{\partial x} = 0$$

- Robert scheme
  - 3 iterations to find origin point
  - bi-cubic interpolation
- Flux limiter
  - local max, min constraint





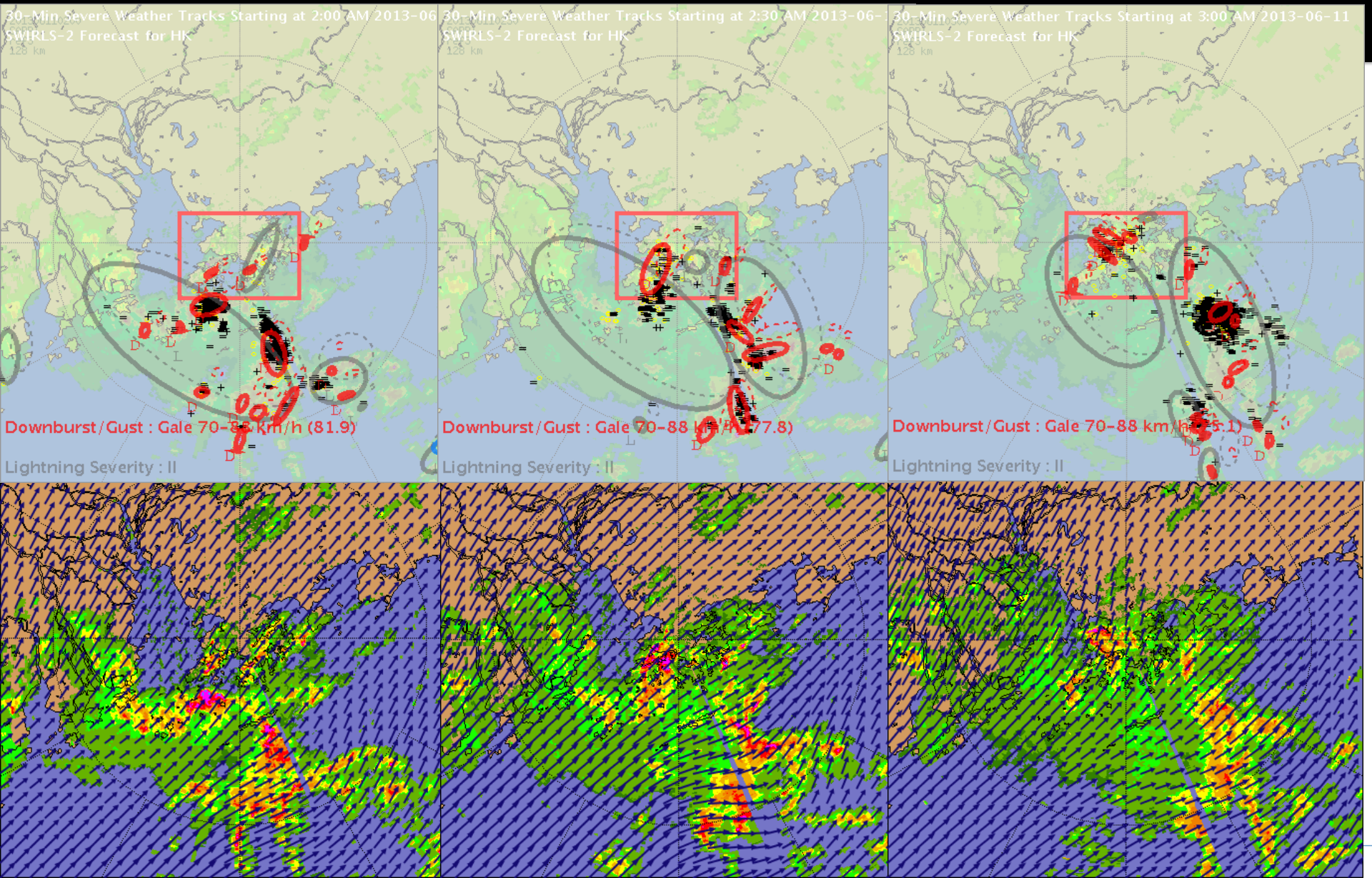
Severe Weather Nowcast in SWIRLS



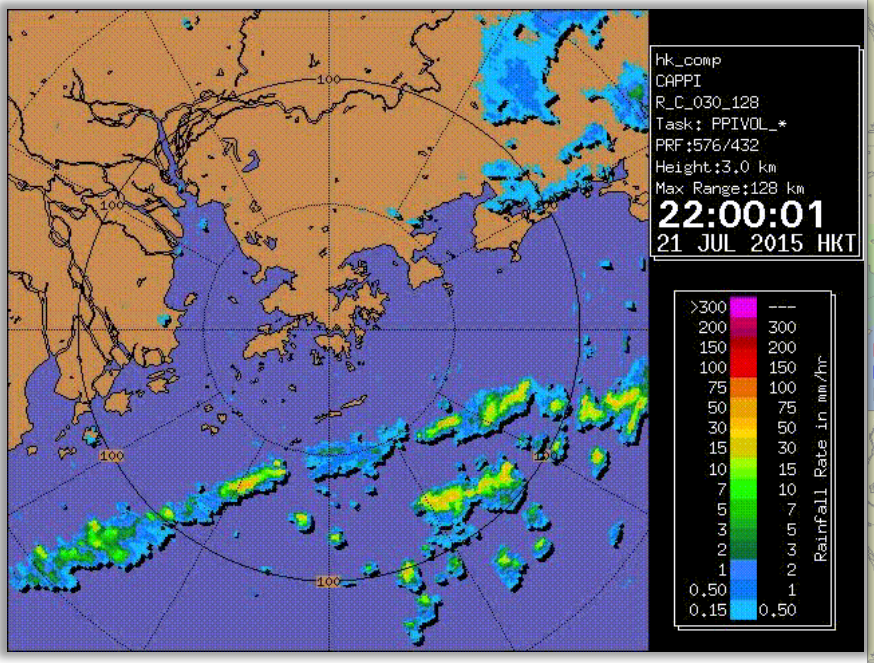
Legend

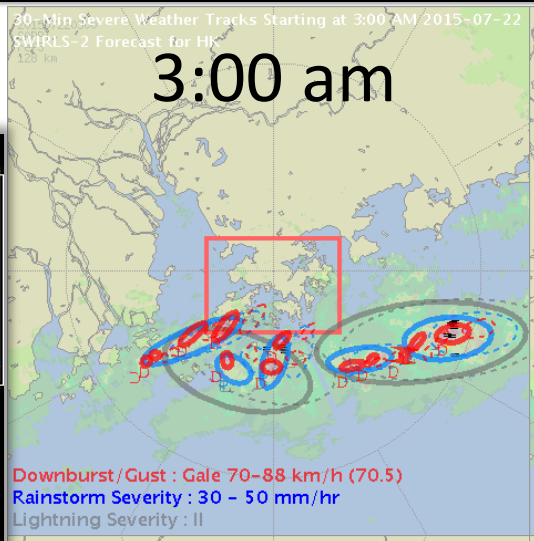
- area with hail potential
- 30-min forecast location of hail
- area with severe gust potential
- 30-min forecast location of severe gust
- area with rainstorm potential
- 30-min forecast location of rainstorm
- area with lightning potential
- 30-min forecast location of lightning
- =/+ detected -ve CG lightning location
- O detected CC lightning location
- Warning area

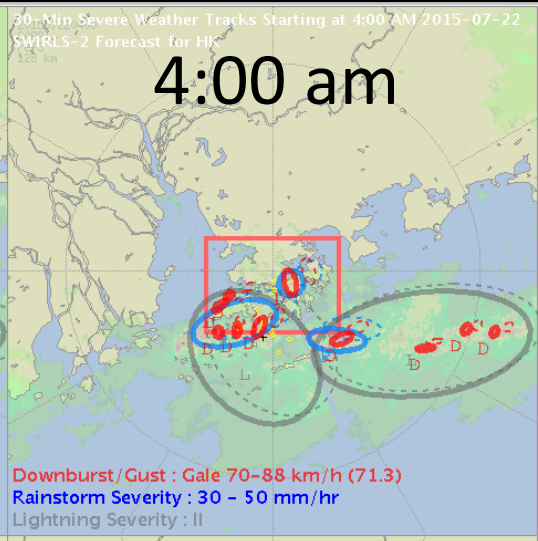
Convective downburst (gust) and lightning (2013-06-11 02:00H – 03:00H)

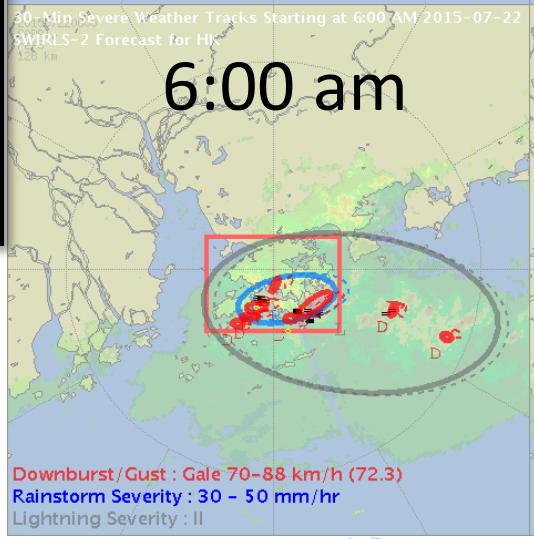


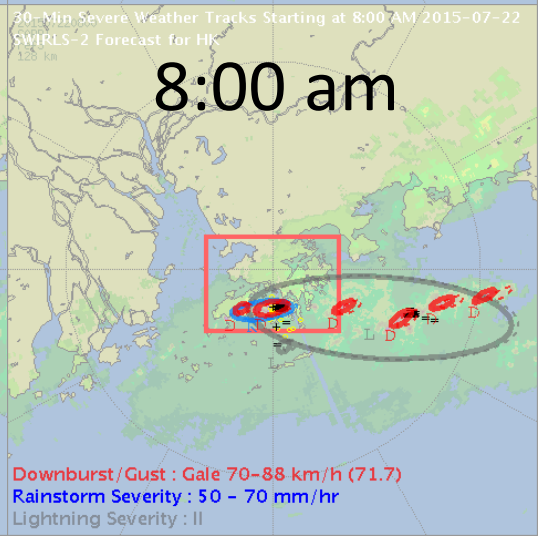
Prolonged developments of downburst, rainstorm and lightning cells during Amber Rainstorm on 22 July 2015





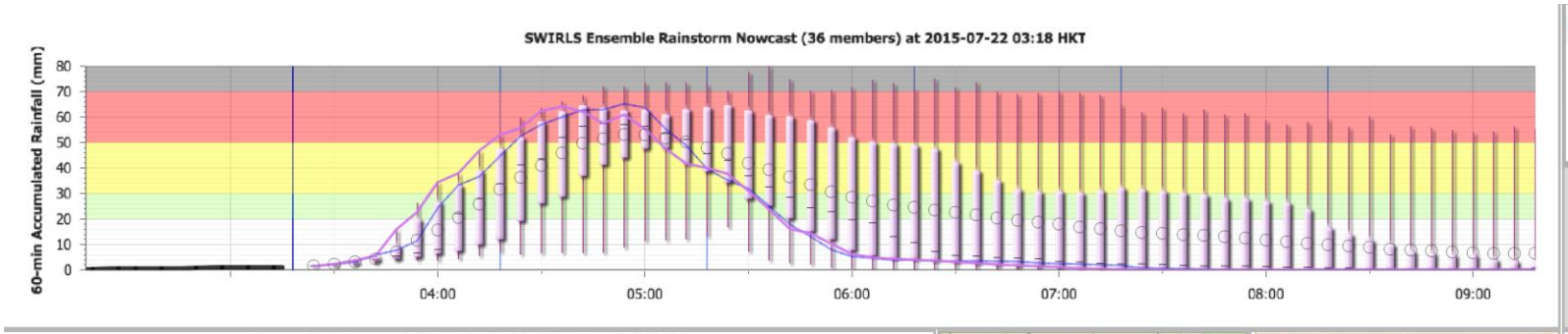


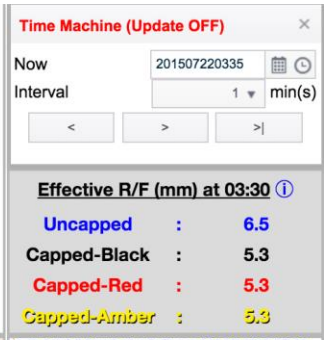


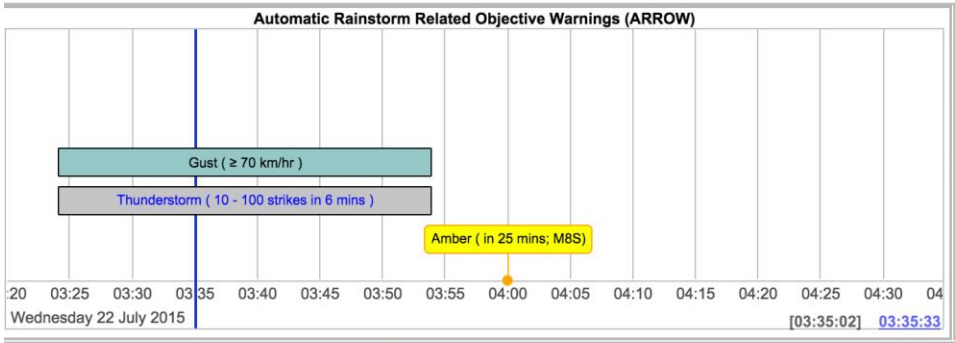


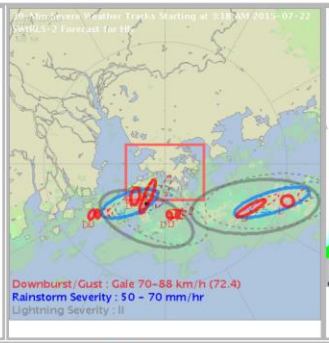
SWIRLS Products for Users

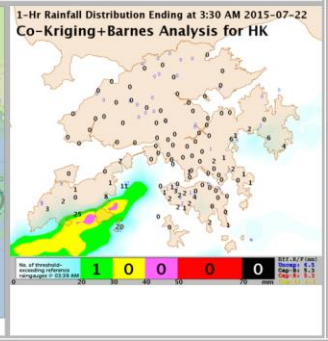
SWIRLS Automatic Warnings and Alerting Information on Likelihood of Rainstorm Warnings

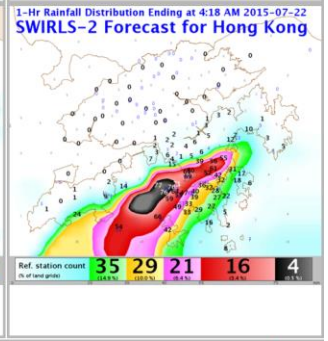


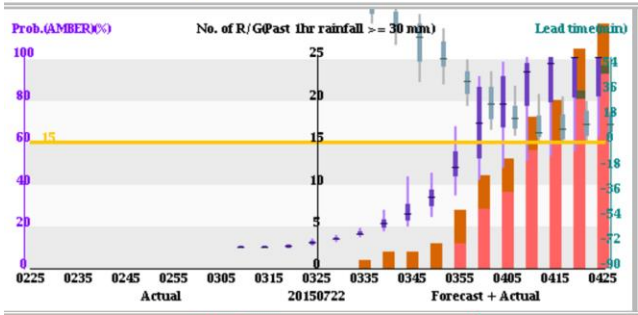


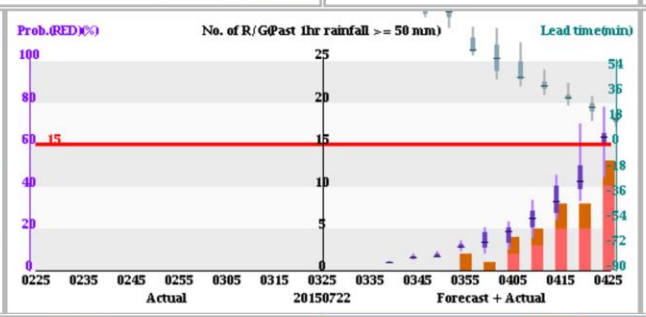


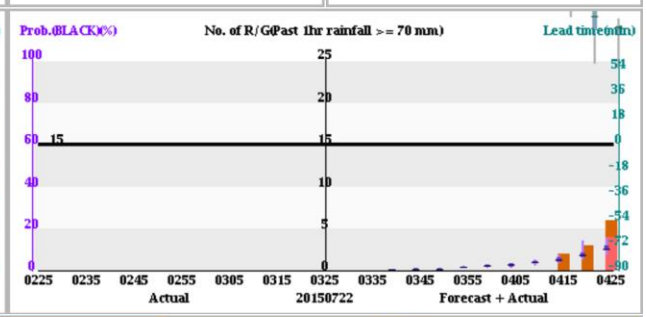










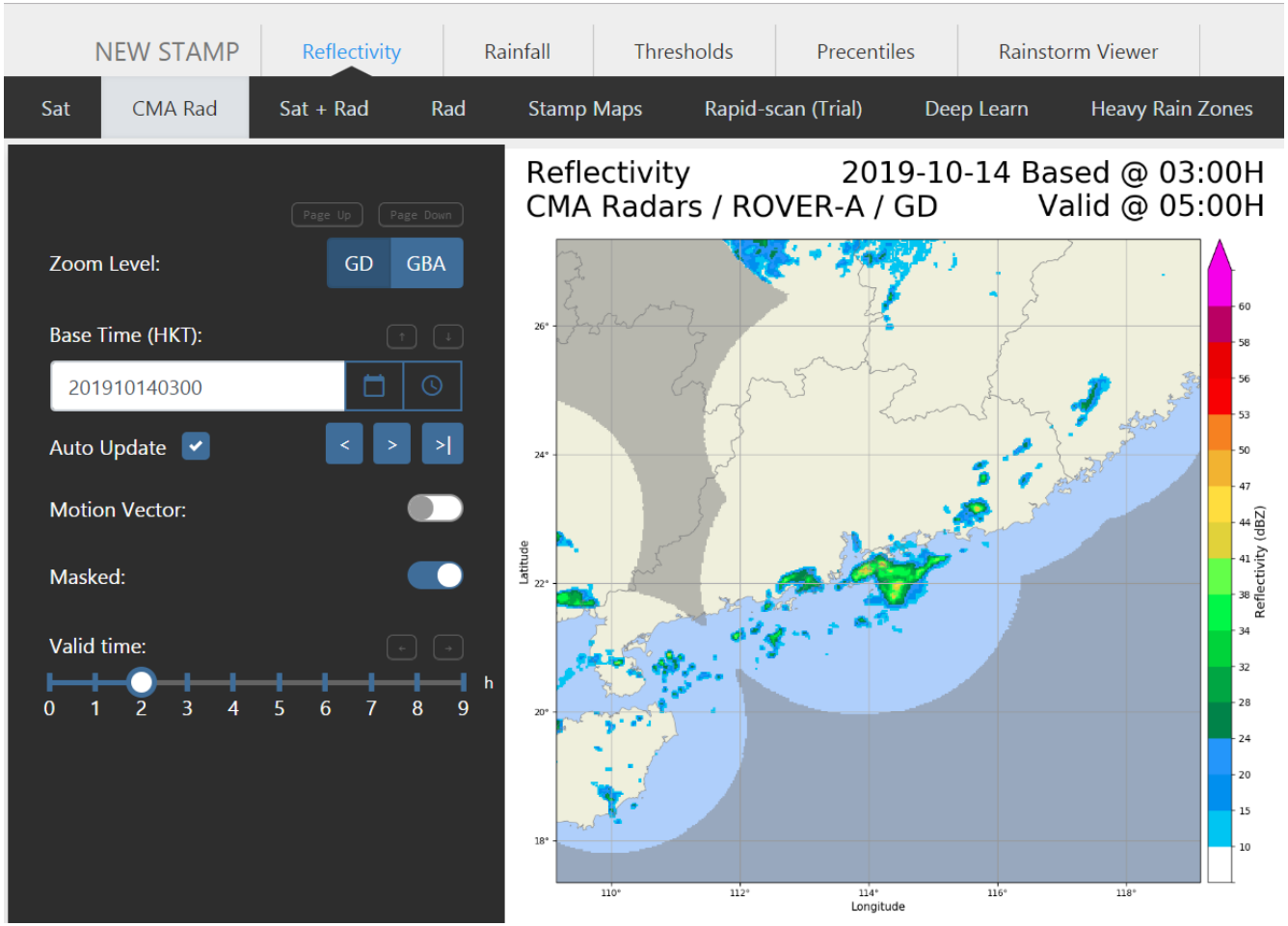


Urban Areas | NT East | NT West | NT North

WMO

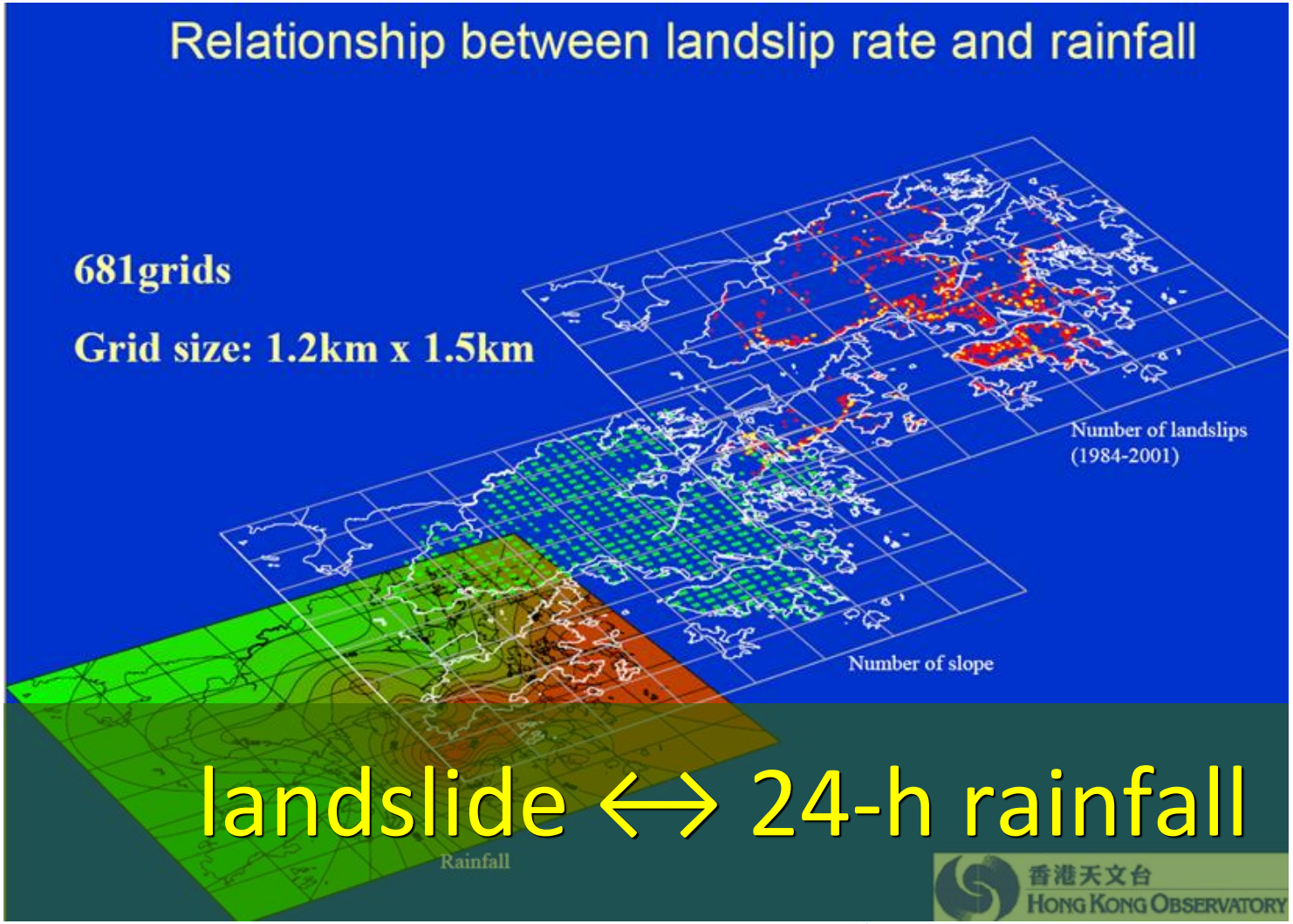
香港天文台
HONG KONG OBSERVATORY

SWIRLS Visualization of Products



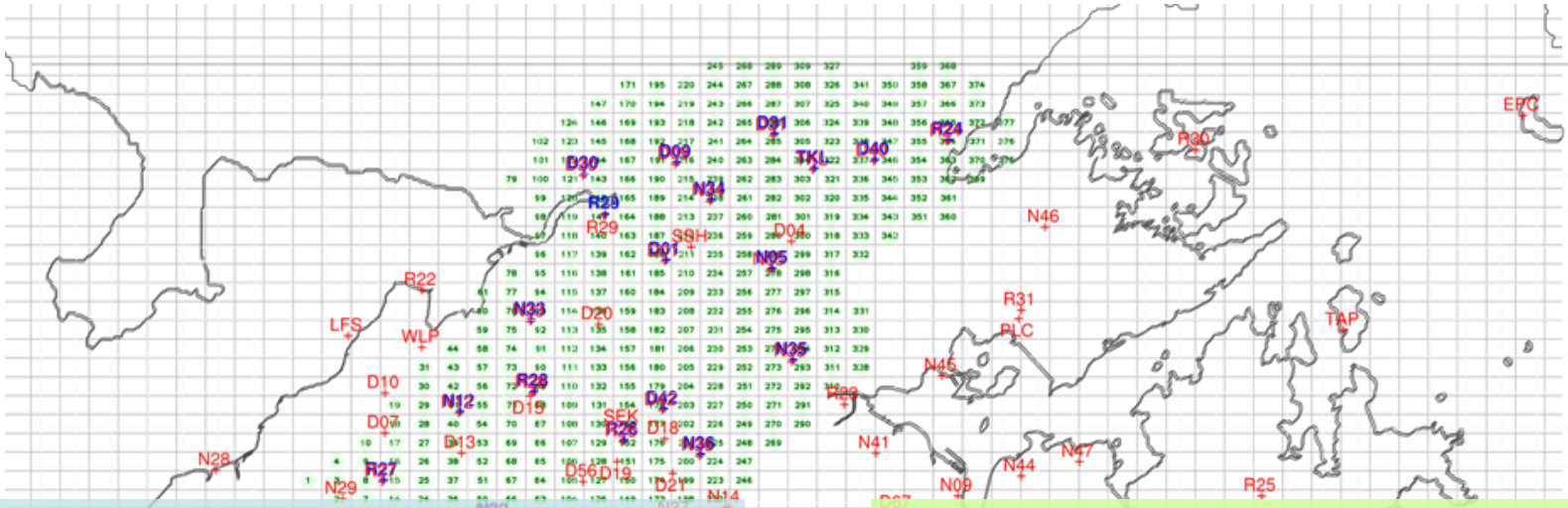
Landslip Warning

- collaboration with Geotechnical Engineering Office



Special Announcement on Flooding

- Drainage Services Department



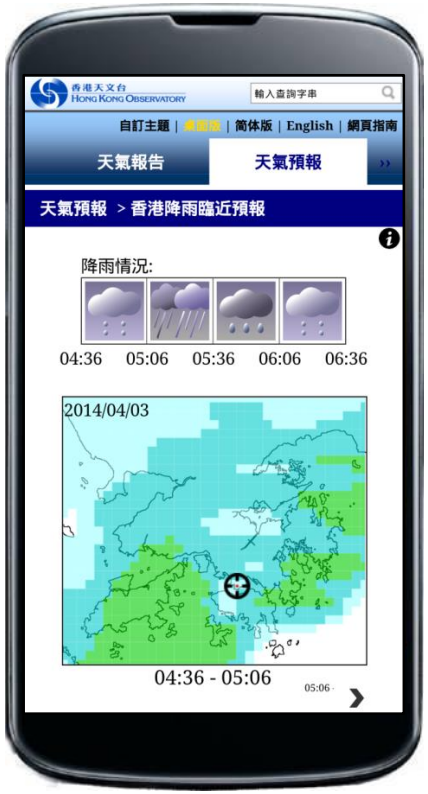
- Special Announcement of Flooding for northern NT
- rainfall threshold-based
  - *19 reference raingauges*
- current rainfall criteria (since 2006)
  - ***70** mm/hr if $R_{24} \leq 100$ mm*
  - ***60** mm/hr if $R_{24} > 100$ mm*
  - *old criteria (1998-2005)*
    - **50 mm/hr &**
    - **45 mm/hr respectively**

- grid-based nowcast
  - *rainfall inputs*
    - ***actual 24-h rainfall :***
    - ***forecast 1-h rainfall from SWIRLS***
- triggering criteria
  - *rainfall thresholds identical to SAFNNT*
  - *~5% (20) grid points or more with forecast 1-hr rainfall exceeding thresholds*

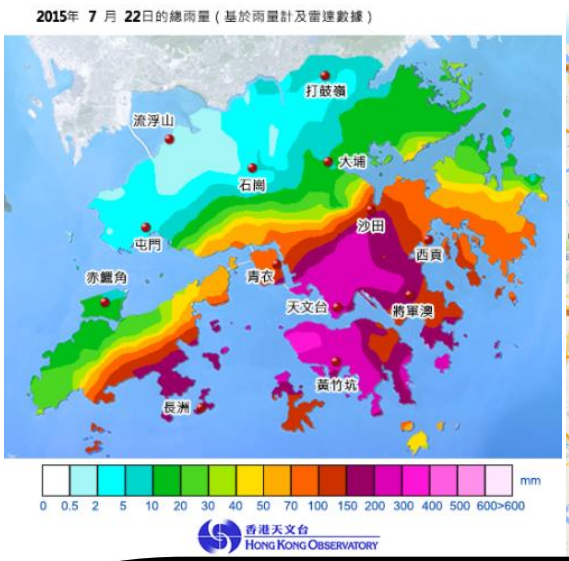
Location-specific Rainfall Nowcast for public

- Personalized rainfall forecast in MyObservatory app (iOS/Android/Windows) and mobile version HKO website
  - automatic alert if rain to occur in next 2 hours at your location

圖二：試驗版「定點降雨預報」的動畫畫面樣本

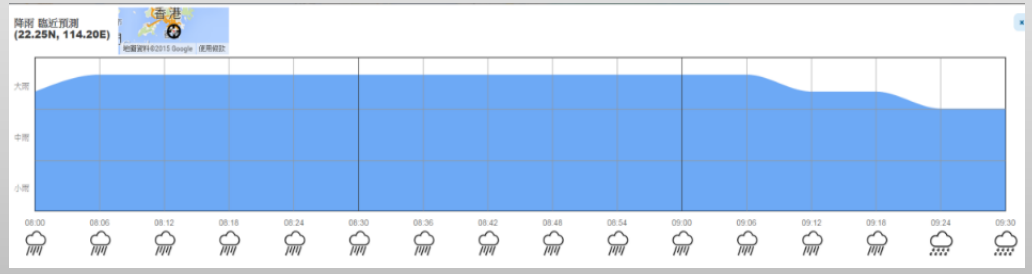


Rainfall Nowcast in Hong Kong and Pearl River Delta Region in the next 2 hours



Rainfall nowcast for the next 2 hours

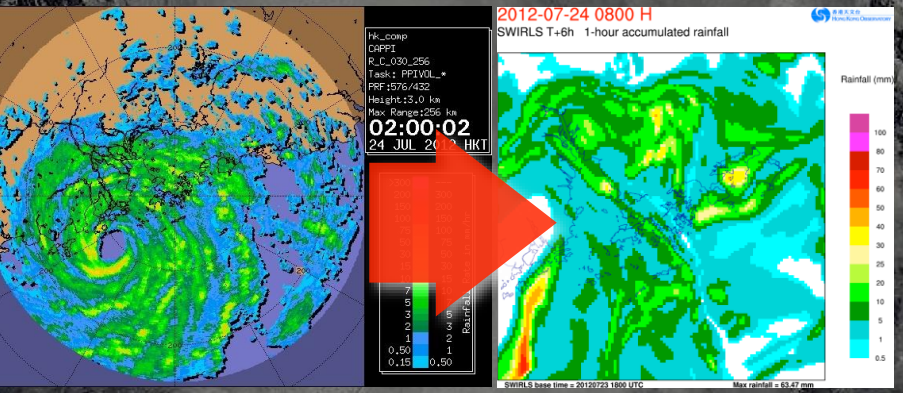
Click for the time series of the nowcast rainfall intensity



On 22 July 2015, the Amber Rainstorm Warning Signal issued by the Observatory lasted for nearly 12 hours and the Landslip Warning was also in force for more than 6 hours. The area of intense rain remained almost stationary over the southern part of Hong Kong for a prolonged period in the morning

Blending QPFs from Nowcast and NWP

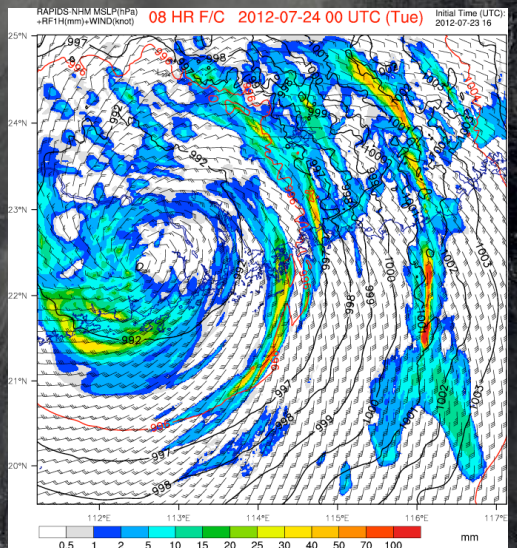
ST Vicente (2012-07-24 02:00 HKT)



SWIRLS-2 radar nowcast (1-6 hr)
(optical flow tracking, semi-Lagrangian advection)

RAPIDS-NHM rainfall forecasts

(1-15 hr)



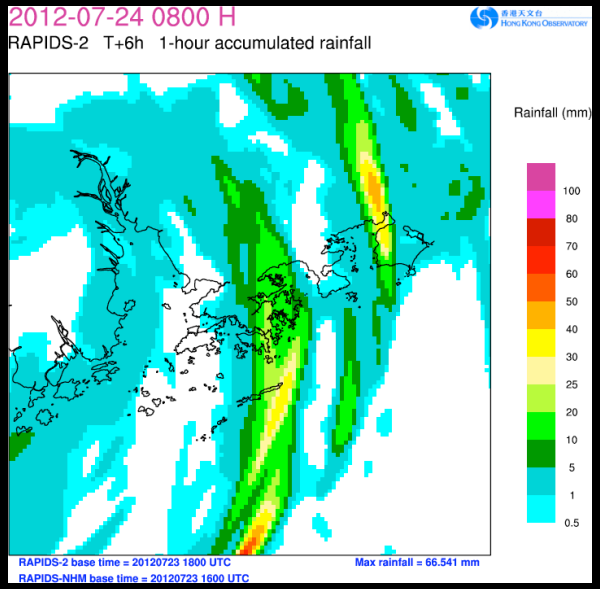
Blending

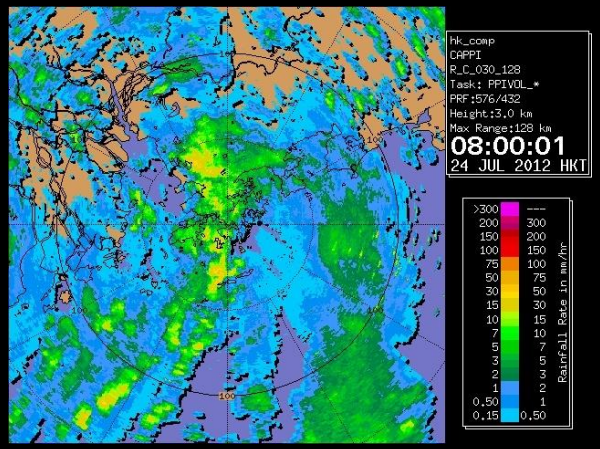
Phase correction of position error of model QPF

Intensity calibration to adjust model rainfall intensity

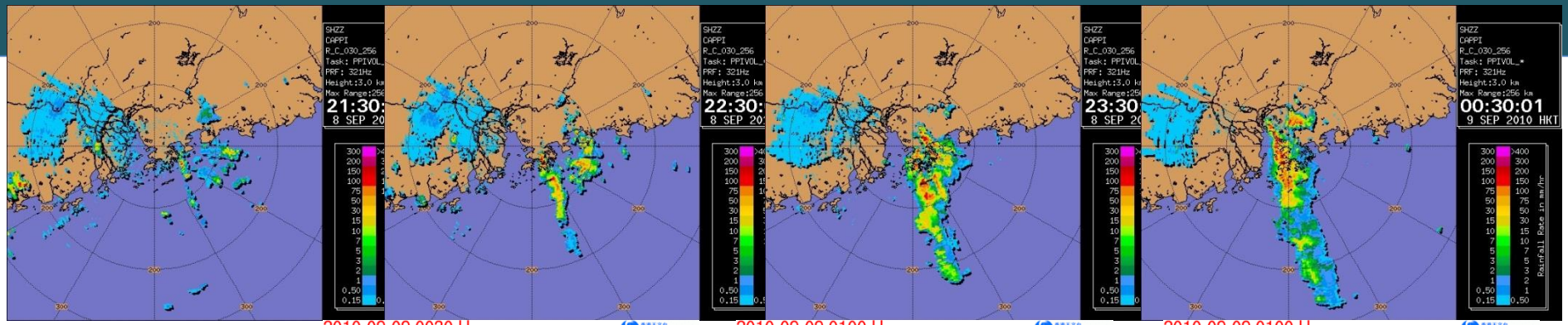
Superposition on radar nowcast using time-dependent weighting

RAPIDS QPF

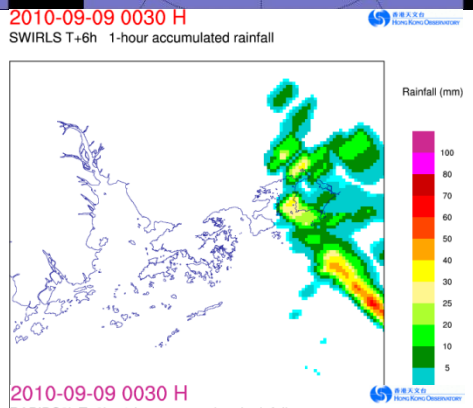


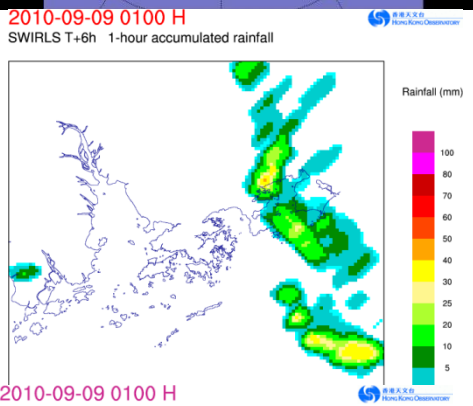


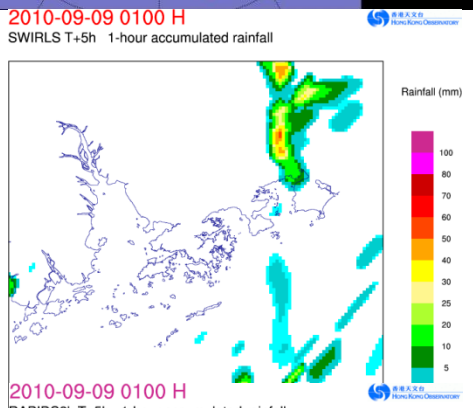
Blending Nowcast and NWP



SWIRLS nowcasts for 00:30 – 01:00H





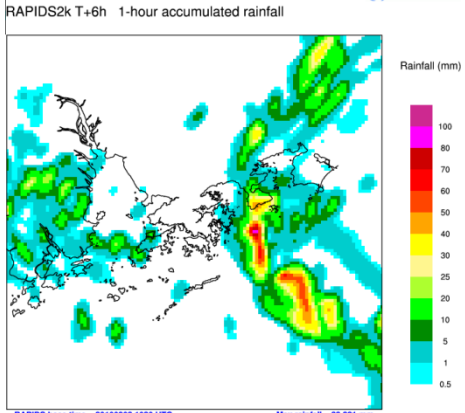


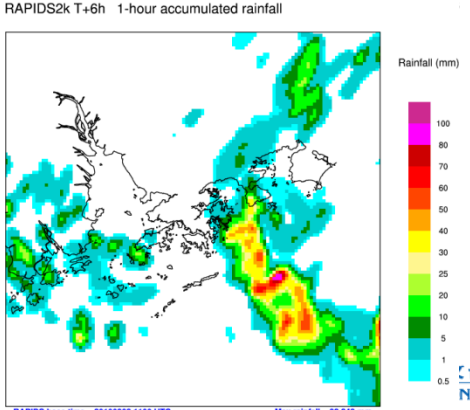
Blending

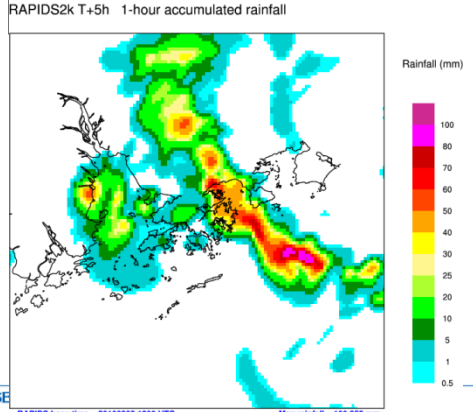
SWIRLS

+

NWP



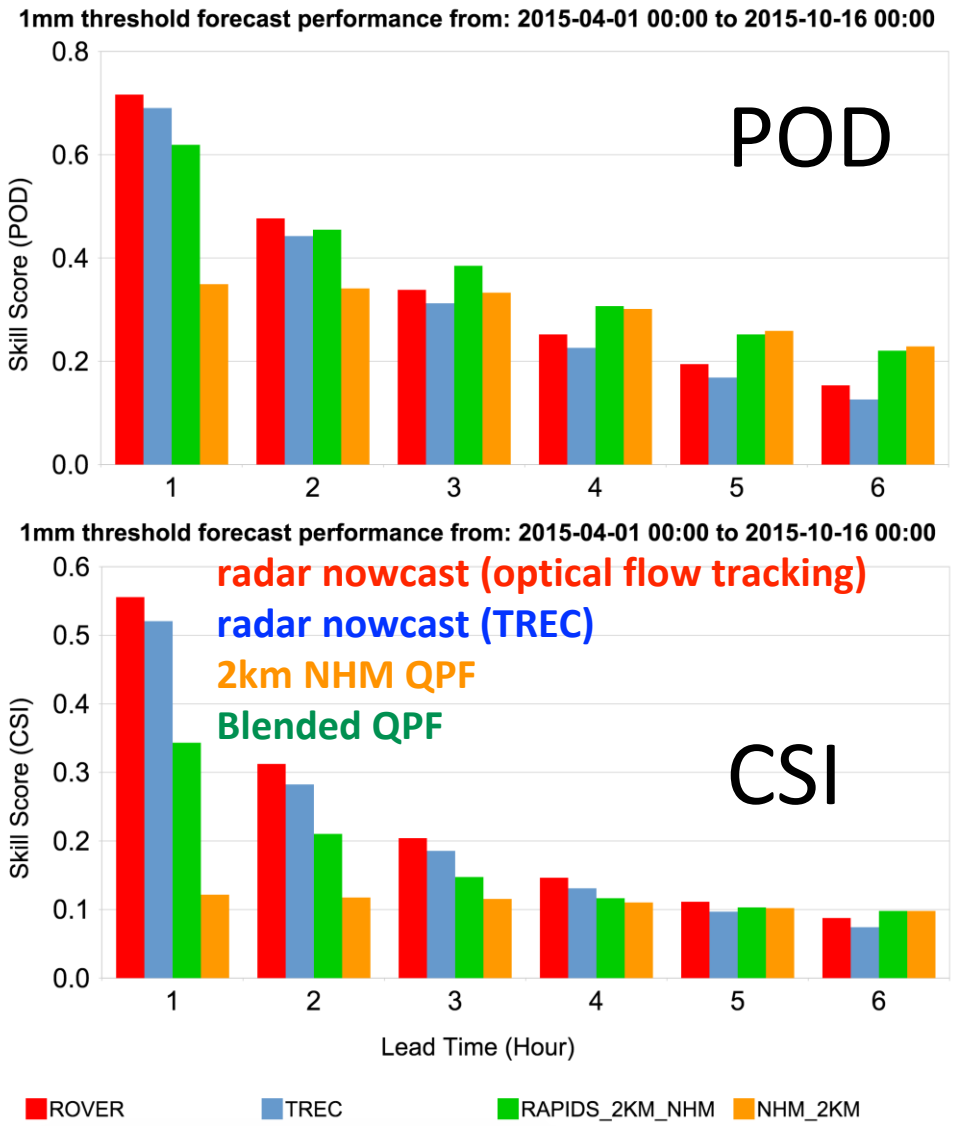




Verification (Apr - Oct 2015)

grid-by-grid verification of QPF (dx = 2 km)
over HK and Pearl River Delta

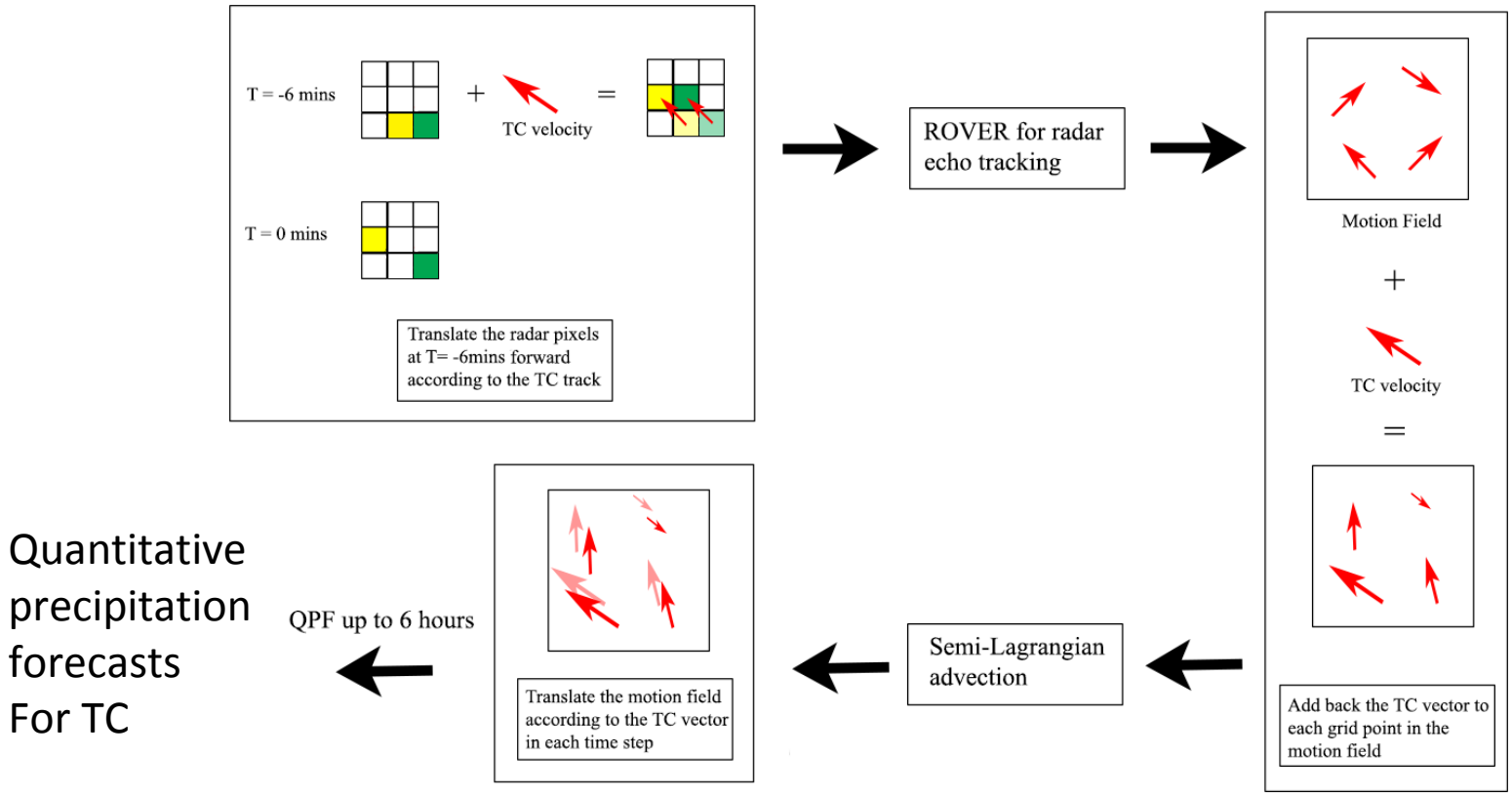
- Blending of radar nowcast and RAPIDS-NHM QPF
  - track motion of radar echoes over successive radar images and extrapolate for 6-9 hours
  - blending with RAPIDS-NHM QPF after correcting phase errors of gridded rainfall forecasts
  - blending of other convective forecast parameters (e.g. significant convection)



TC Module in SWIRLS

Typhoon Committee Research Fellowship 2012

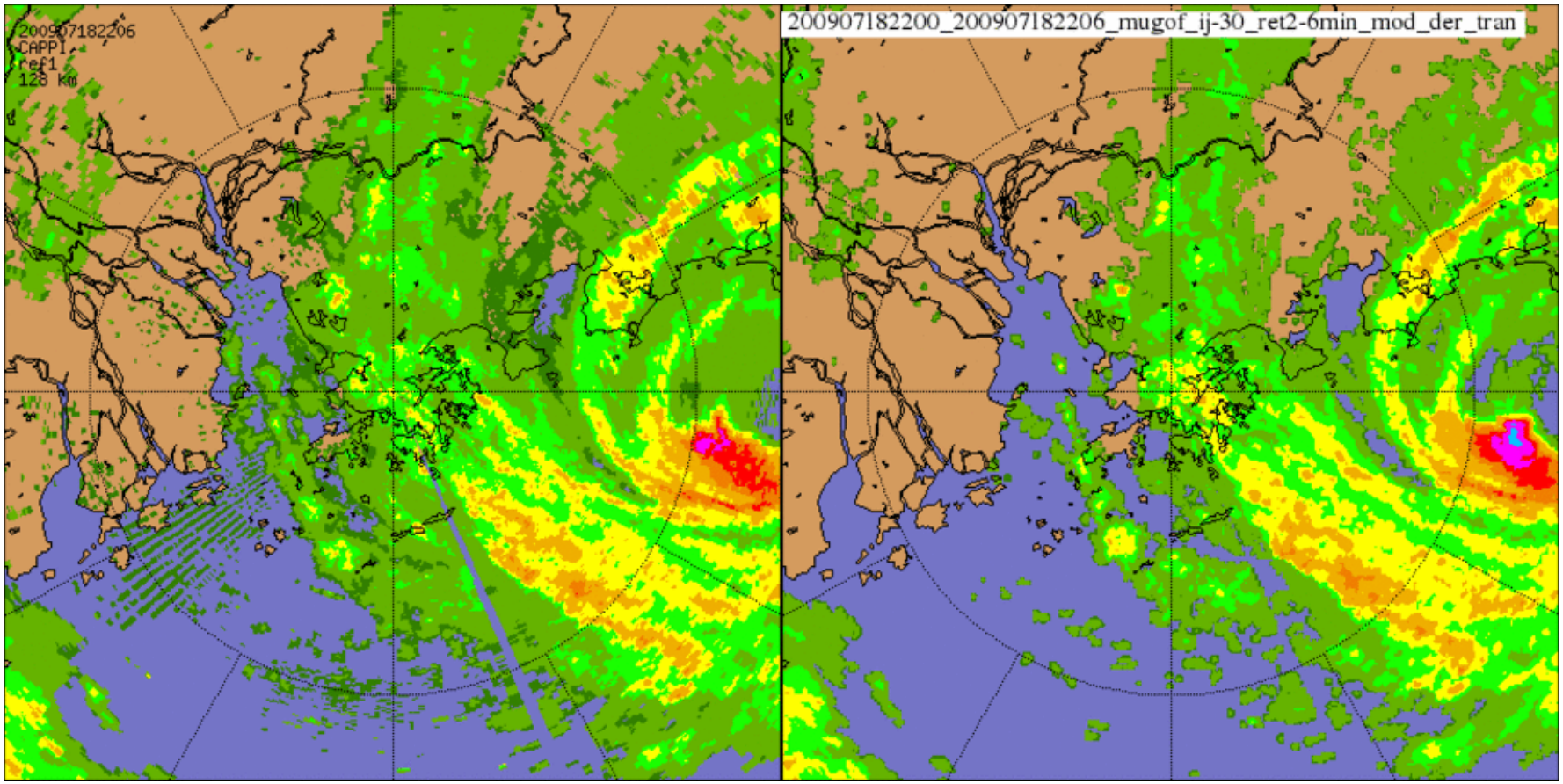
- Enhancement of echo tracking algorithms in SWIRLS



TC Nowcast Module

ACTUAL

Forecast using TC Module



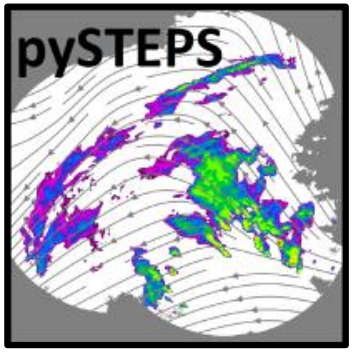
Community SWIRLS Nowcasting System (Com-SWIRLS)

Nowcasting Systems

Library	Language	Website	Availability
com-SWIRLS	Python	https://com-swirls.org	free license
IMPROVER	Python, Shell	https://improver.readthedocs.io	open source
INCA	C, Fortran, Shell	https://www.zamg.ac.at	free license
pysteps	Python	https://pysteps.github.io	open source
rainymotion	Python	https://github.com/hydrogo/rainymotion	open source
STEPS	C, C++	https://www.bom.gov.au (Alan Seed)	free license

Pysteps

Curriculum vitae



https://pysteps.github.io/

Personal details

Name:	pysteps
Conception:	10-12 October 2017, *SixS workshop, MeteoSwiss, Locarno-Monti*
Birth date:	June 2018 (8 months later... premature?)
Nationality*:*	Multi-cultural (CH, FIN, CAN, AUS, etc)
Family:	Seppo (father), Daniele (mother), Andrés (1st friend), Carlos (cousin) Alan (grand-father), Urs (grand-mother), Loris (obstetrician)
First encounters:	*1 July 2018, ERAD conference, Wageningen, NL* https://www.erad2018.nl/short-courses/

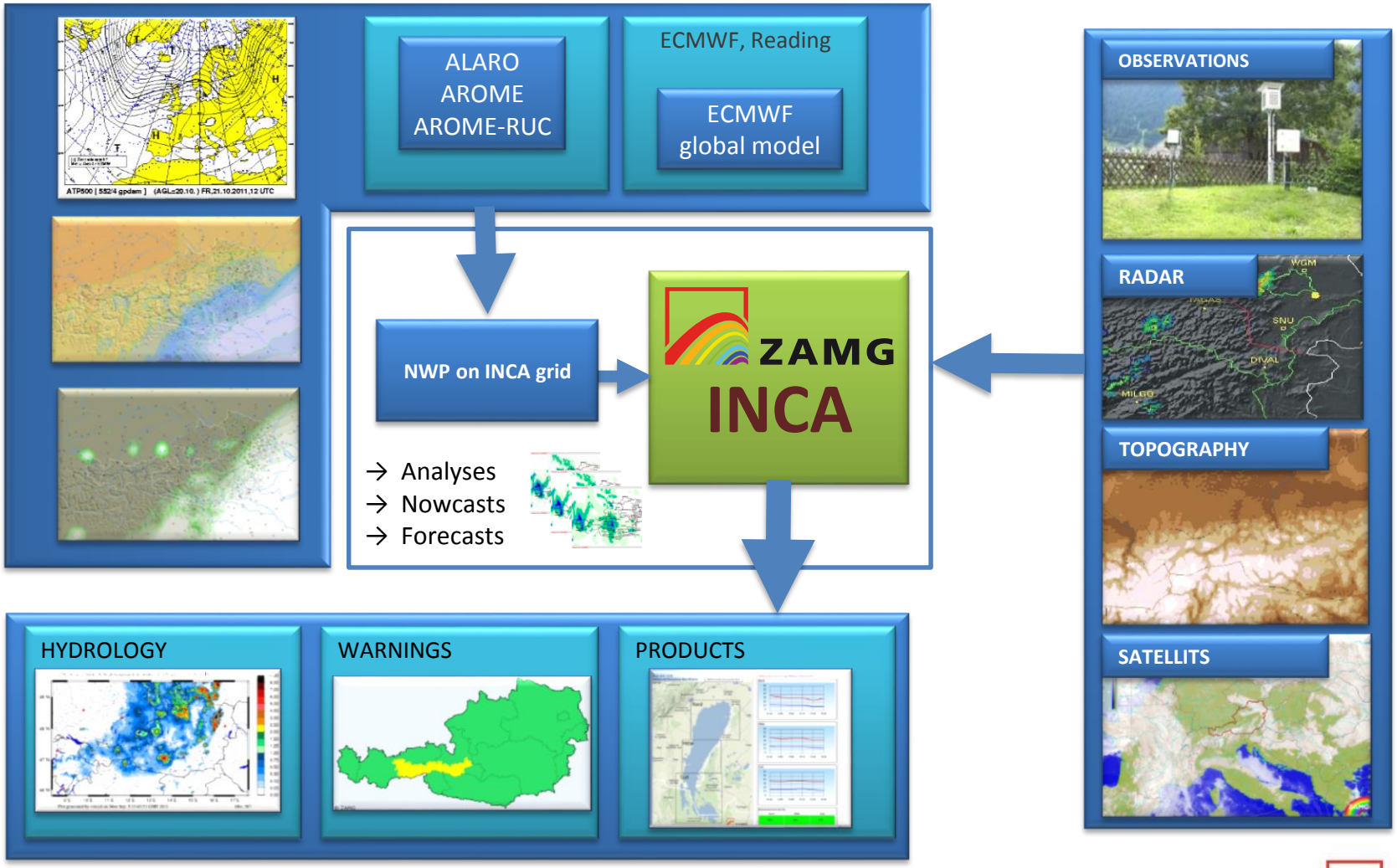
Technical and soft skills

Languages:	Python, some Cython
Character:	Open, likes feeling used, a bit unpredictable
Career goals:	Make heaps of friends and become their leader

Funding received

- SNSF Ambizione project: *Precipitation attractor from radar and satellite data archives and implications for seamless very short-term precipitation forecasting*.
- FMI funding to support visit of Seppo Pulkkinen at MeteoSwiss

INCA System Overview

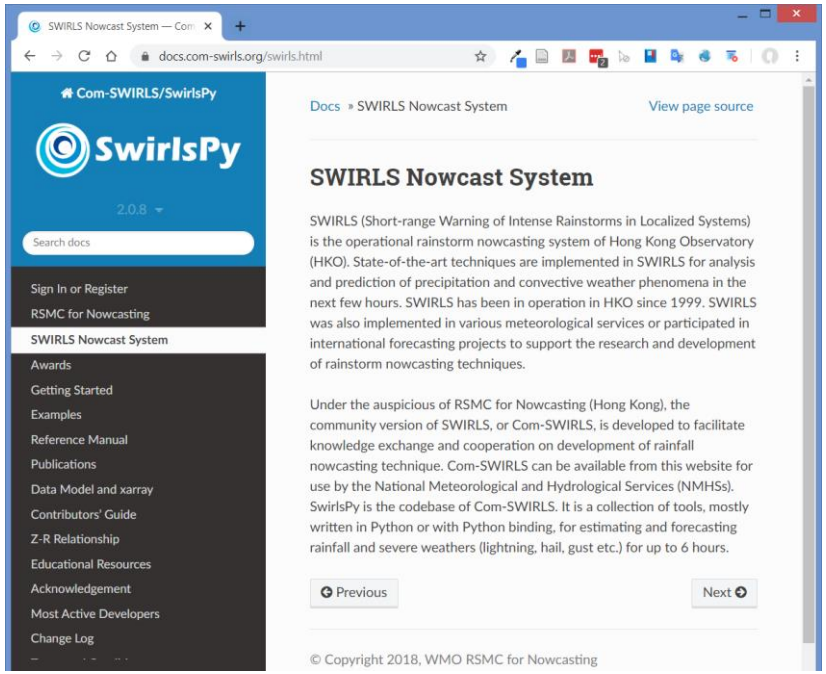


Haiden T, Kann A, Wittmann C, Pistotnik G, Bica B, Gruber C., 2011: The Integrated Nowcasting through Comprehensive Analysis (INCA) System and Its Validation over the Eastern Alpine Region. Weather and Forecasting, 26/2, 166-183,

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Com-SWIRLS

- A Service of RSMC for Nowcasting (Hong Kong)
- To facilitate knowledge exchange and collaboration
- Freely shared with all National Meteorological & Hydrological Services (NMHS)
- Source codes included
- Codename: ***SwirlsPy***



https://com-swirls.org/

Features of Com-SWIRLS 2.0

- Continuously Maintained and Updated
- Installable by Conda, Single Command
- Documentation Website with User Examples
- Readable Codes, Reusable Modules
- Version Control with GitLab
- Technical Support & Discussions by GitLab Issues
- Support Various Radar Data Formats
- Various QPE Interpolation Methods
- Numerous Motion Field and Forecast Algorithms
- Verification Metrics

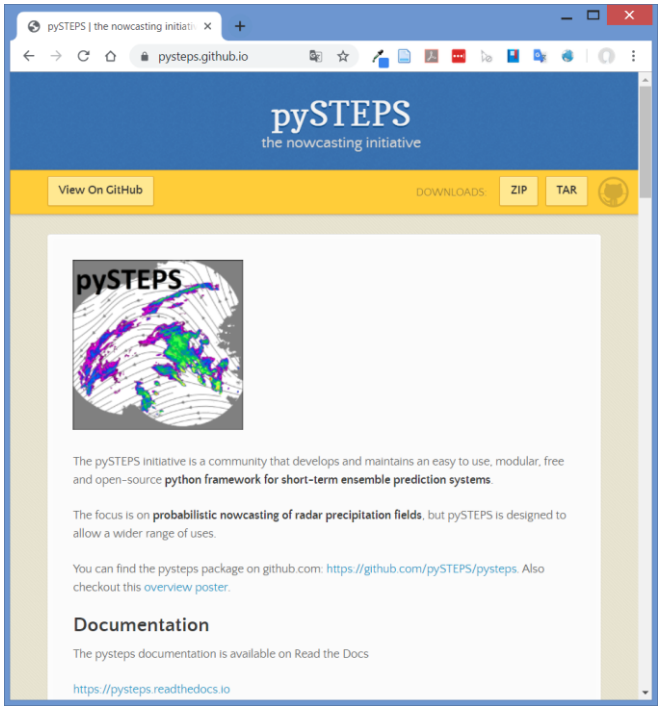
Com-SWIRLS 1.x vs 2.0

	Com-SWIRLS 1.x	Com-SWIRLS 2.0
Installation	VM	Conda *
Programming Language	Assorted	Primarily Python, plus C++
Libraries	NCL, ImageMagick etc.	Open-source Python lib.
Grid Size	480x480 Only	Rectangular grid of any size
Supported Radar Data	1	8
Motion Field Algorithms	1	5
Forecast Algorithms	1	5
QPE Methods	1	14, plus multi-sensor QPE
Verification Metrics	No	14
Documentation	Limited	Full Documentations
Version Control	No	Yes, using GitLab-CE
Software Testing	At initial development only	Upon any changes

* VM and Docker available on request

Use of Open-Source Libraries

- wradlib, Metpy etc.
- Py-ART by ARM of DoE(USA)
- Cartopy by UKMO
- pySTEPS



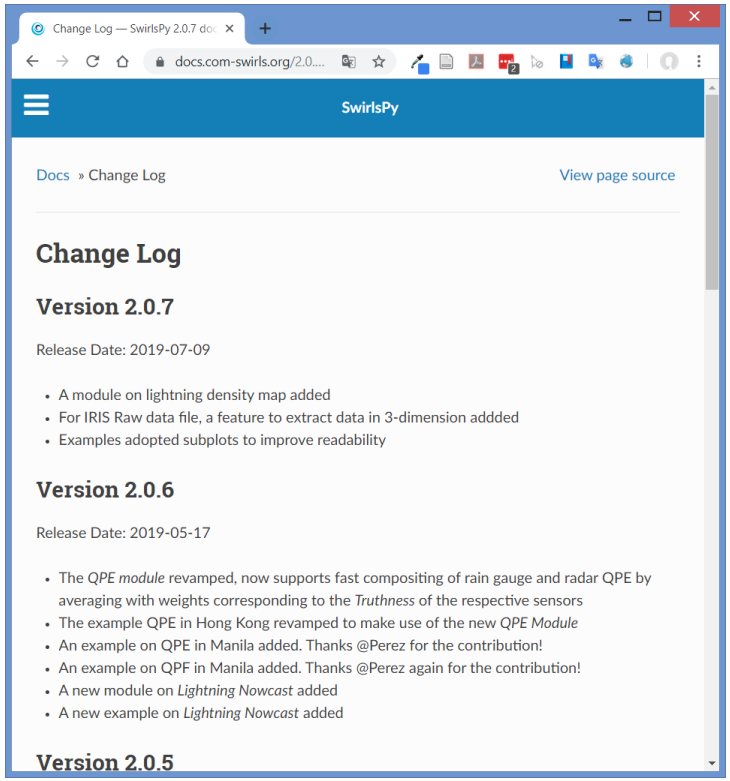
Maintained and Updated Codebase

Updated every
One or Two Months

- For
  - Bug Fix
  - New Features
  - Documentation Update

- Releases:
  - 2.0.8: 2019-09
  - 2.0.7: 2019-07-09
  - …
  - 2.0.0: 2018-12-19

Change Log



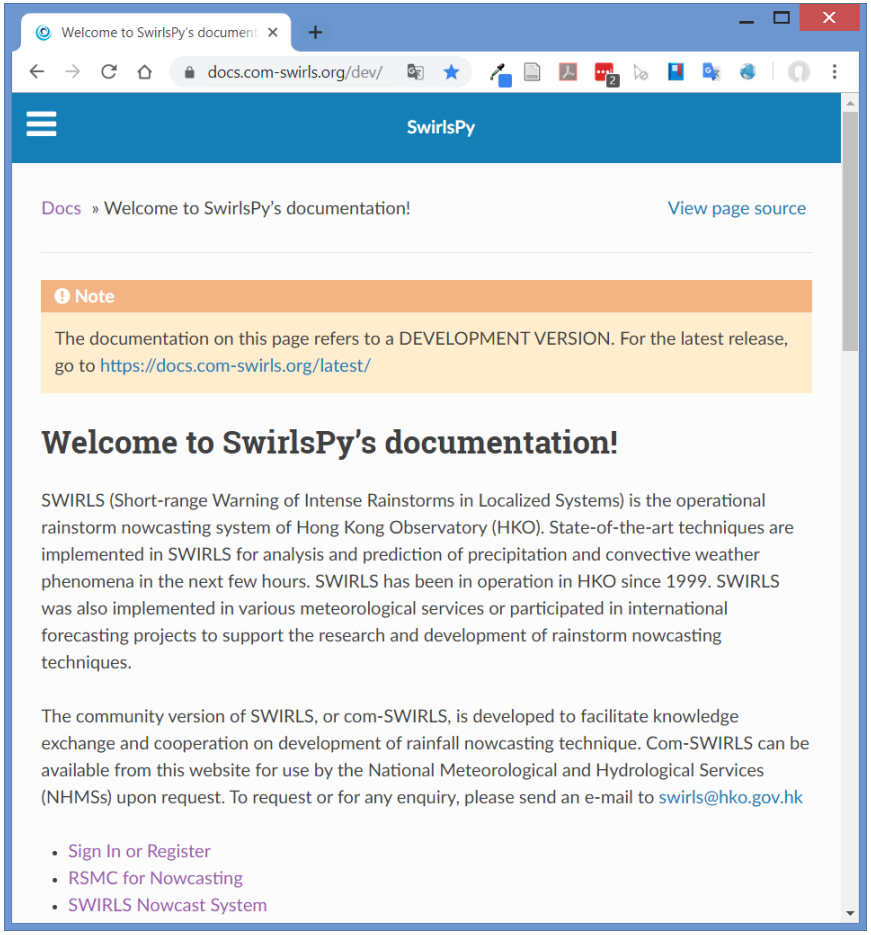
Distribution and Installation

- Distributed as Conda packages
- Can be Installed with Single Command:

```
conda create -n swirlspy
  -c https://2018:314159@conda.com-swirls.org
  -c defaults -c conda-forge swirlspy
```

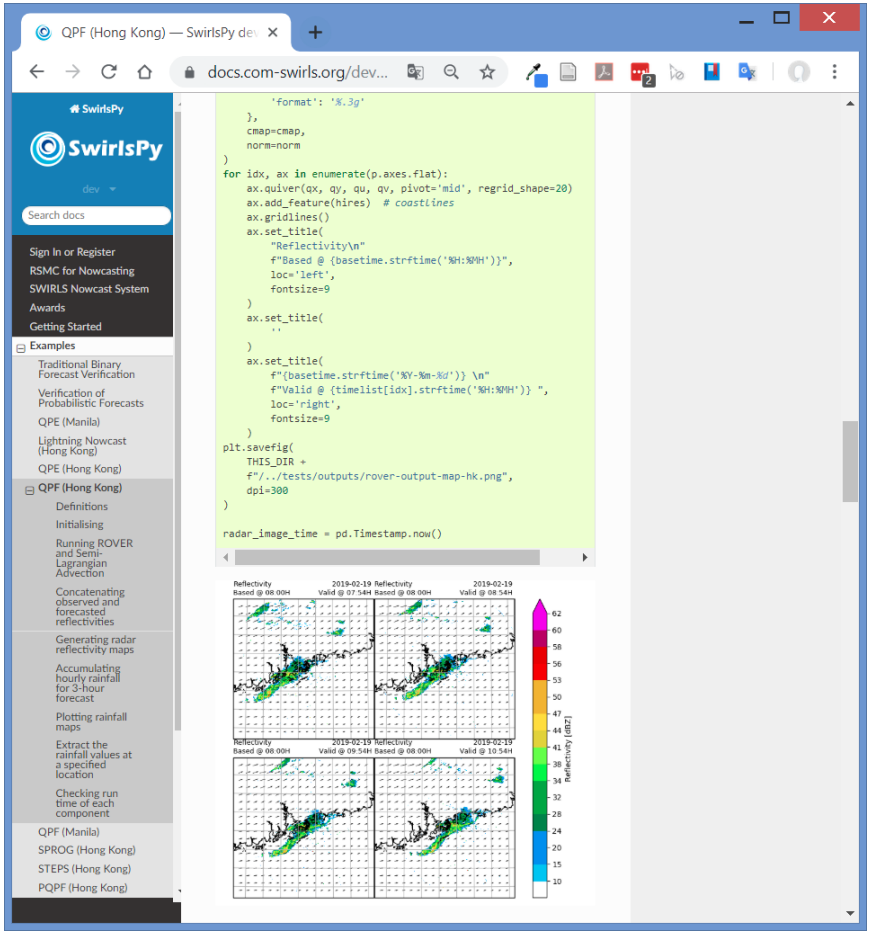
- Virtual Machine (VM) and Docker Images available upon request

Documentation with Examples



Documentation Website

https://docs.com-swirls.org/



Example User Codes

Readable Codes, Reusable Modules

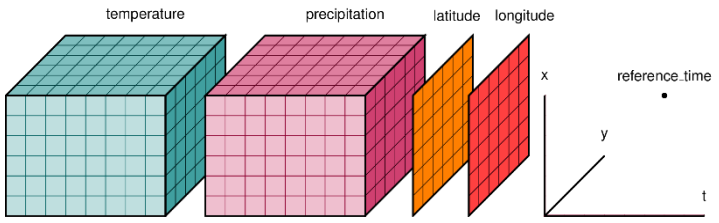
What's up with "Python"?

***Readable Syntax**

Python	Other language
if a is not 5 :	if (a != 5) { ...
if a is 5 :	if (a == 5) { ....
while (*a* is True and *b* is False) : python code	while (a == true && b == false) { ....other code }
while (a is True or B is False) :	while (a == true || b == false) { ...
print "hi there"	console.log("hi there")
not penjee.isWater(ahead)	! penjee.isWater(ahead)

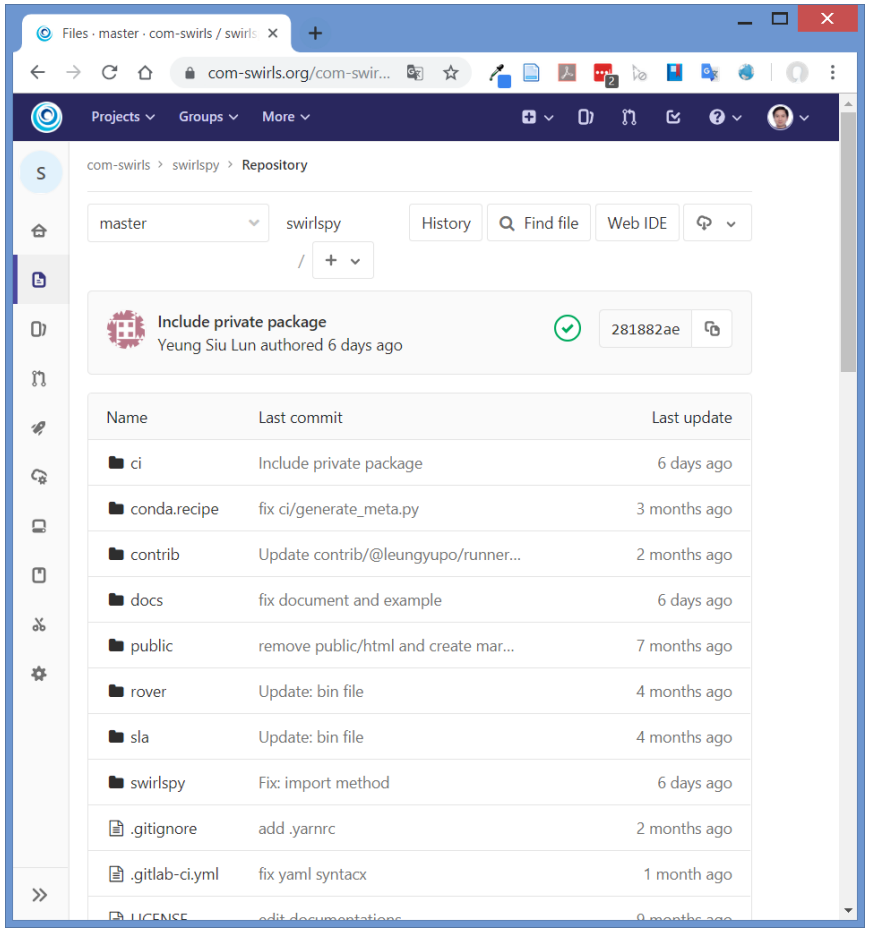
- Adopted Python, a highly readable programming language
- Supplemented with C++ for performance-critical components

Use of ***xarray***, a labelled multi-dimensional array data structure, as the common data model between modules

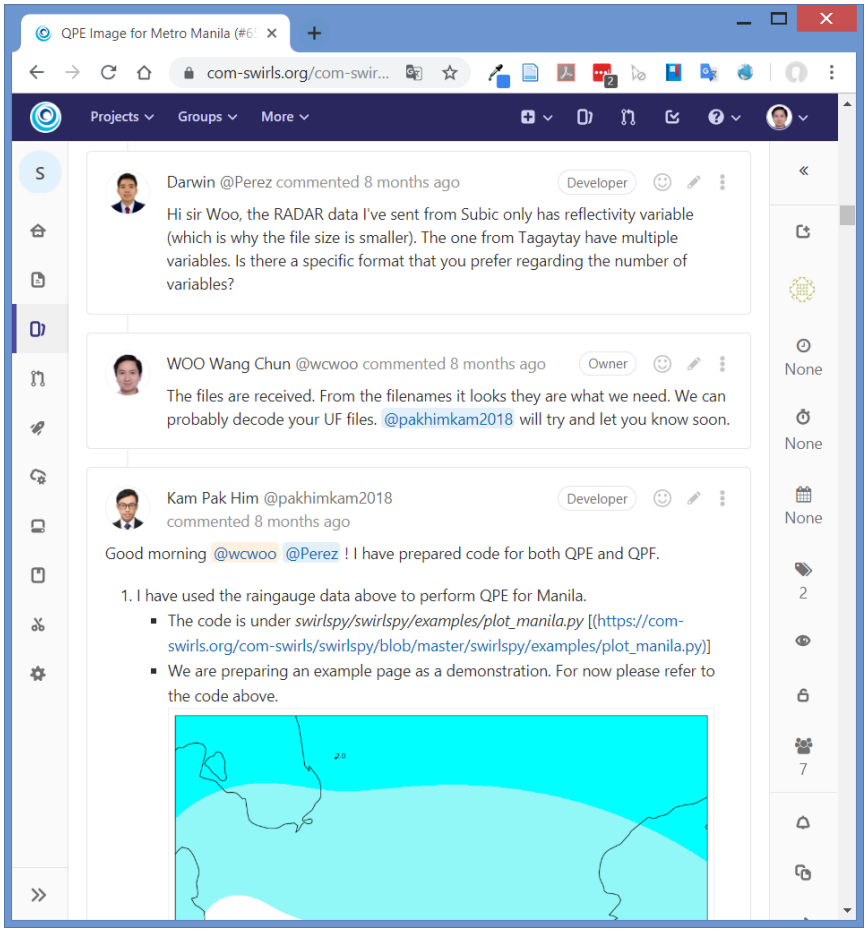


Version Control with GitLab

- HKO running GitLab-CE, an open-source software development platform
- Version Control, enabling simultaneous developments by staff & contributors
- Continuous Integration (CI) for automated tests
- Continuous Deployment (CD) for automated packaging and documentation generation



GitLab's Issues

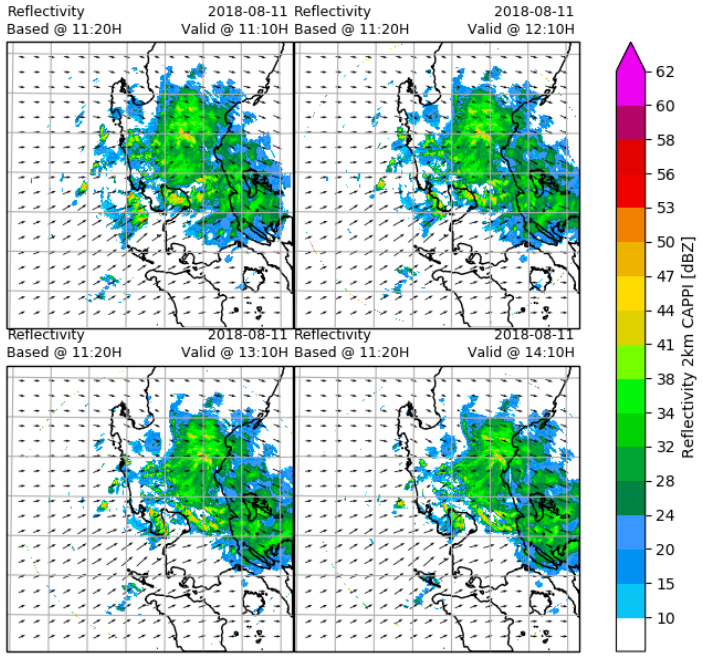


- Facilitates Technical Support and Idea Exchange
- Any user can create an issue, HKO's team will respond asap
- Also useful for recording **Merge Requests**
- Past issues are searchable, thus becoming a ***Knowledge Base*** in the long run

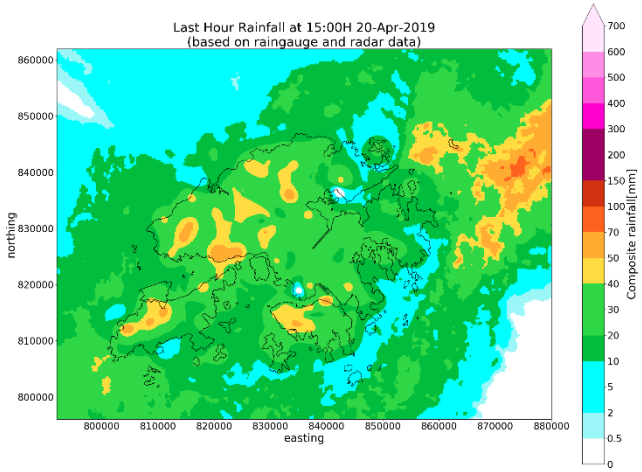
Various Radar Data Format

Supported Formats

- ASCII (ESRI's)
- CINRAD (China)
- IRIS
  - Raw
  - Reflectivity
- HDF5
- NetCDF
  - A variant for Philippines
  - Two variants for Vietnam
- UF



Various QPE Algorithms



Multi-Sensor Precipitation Estimator

Spatial Interpolation Methods:

- Linear
- Nearest
- Cubic
- RBF
  - multiquadric
  - inverse
  - gaussian
  - linear
  - cubic
  - quaintic
  - Thin_plate
- Natural Neighbour
- Barnes
- Cressman
- Ordinary Kriging

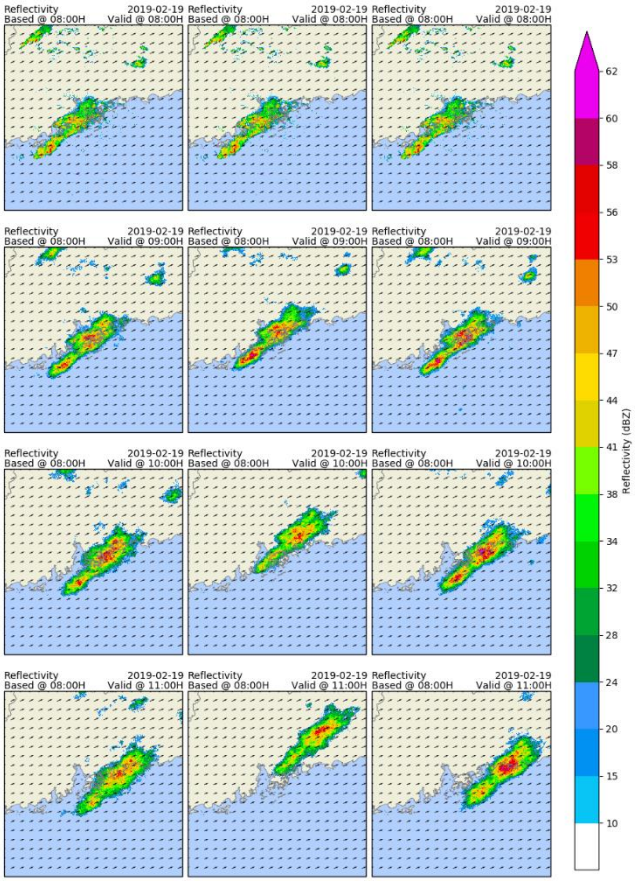
Various QPF Algorithms

Motion Field Generation

- Persistence
- ROVER
- Constant
- DARTS
- Dense Lucas-Kanade
- VET

Forecast Algorithm

- Simple Advection
- Semi-Lagrangian Advection
- SPROG
- SSEPS
- STEPS



QPF by STEPS

Various Verification Metrics

Traditional

- POD
- FAR
- CSI
- Accuracy
- Frequency Bias
- ETS
- HSS
- POFD

Advanced

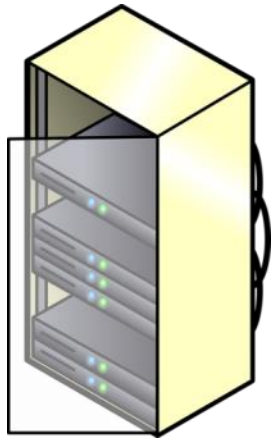
- FSS
- Brier Skill Score
- F1 Score
- Precision – Recall
- Reliability
- ROC

From In-House Development To Collaborative Development

Community SWIRLS

Past

Radar Processing
Rainfall Estimate & Forecast
Visualisation & Guidance



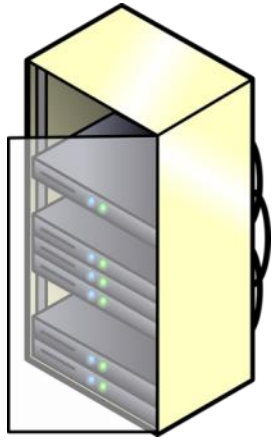
Future

Lead & Coordinate

Radar Processing

Rainfall Estimate & Forecast

Visualisation & Guidance



Future Plan

- More Radar Data Format, e.g. Rainbow
- More QPF Algorithms
- Nowcast with Satellite Data
- Integrated Precipitation Estimator for QPE
- Lightning Potential Nowcast
- Blending with NWP outputs

Support Services for Users

- Online Technical Support:
  - Email (swirls@hko.gov.hk)
  - GitLab Issues
- Cusomitzation:
  - Modules
  - Examples
- Training Workshop
  - Hosted by HKO
  - Served as Expert Lecturer
- Training Attachment
  - 2 weeks – 2 months

Register Now

- https://com-swirls.org/