香港天文台
HONG KONG OBSERVATORY

Nowcasting and Community SWIRLS

SWFDP-SeA RFSC Training Desk, Hanoi, Vietnam

16 – 20 December 2019

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Overview

- On Nowcasting
- SWIRLS in Hong Kong
- Community SWIRLS (Com-SWIRLS)
- WMO RSMC for Nowcasting
- Latest Developments

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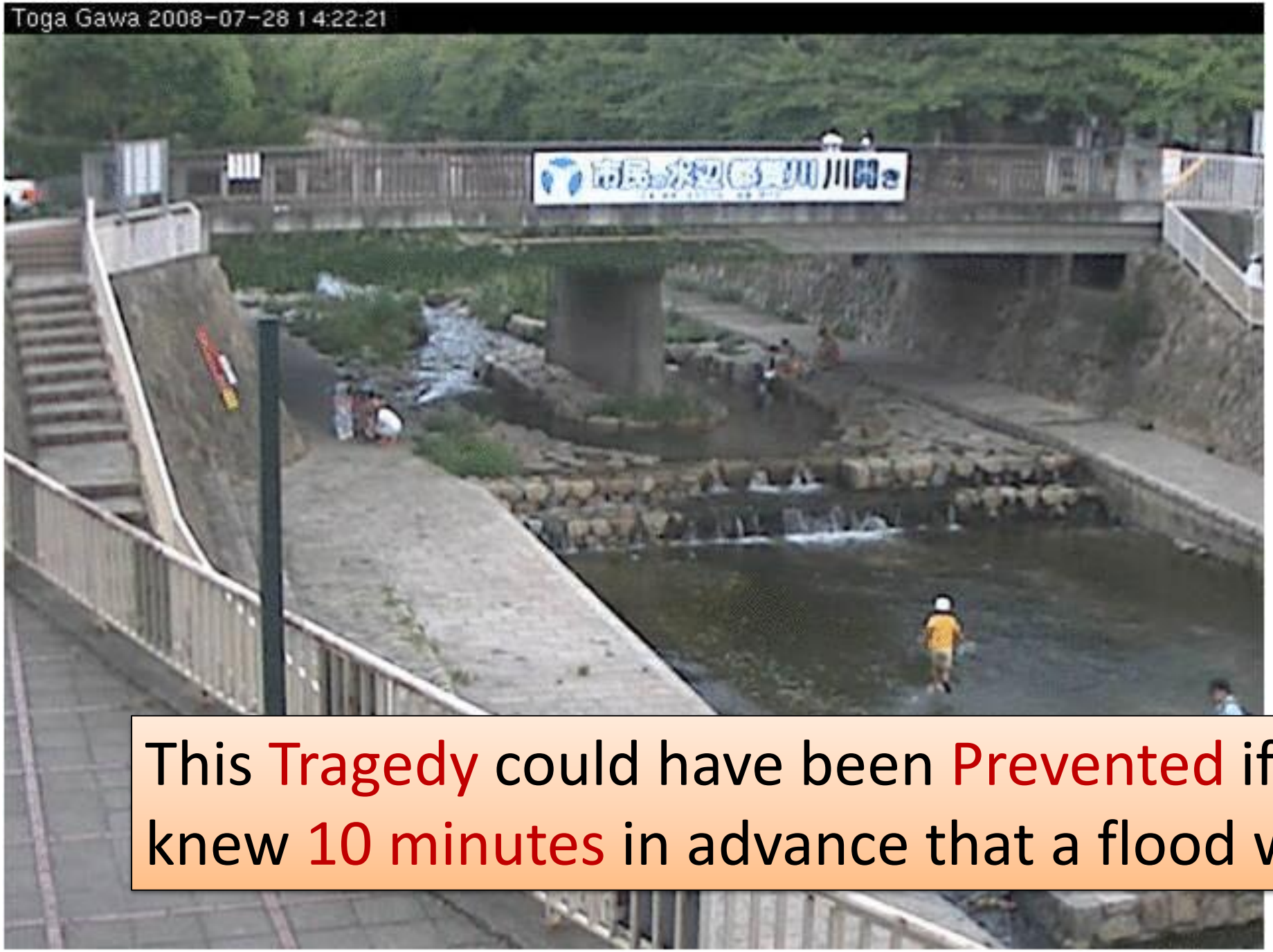
ON NOWCASTING



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Kobe
Japan
July 2008

50 People Washed Away

5 Died

This Tragedy could have been Prevented if only they knew 10 minutes in advance that a flood was coming.

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Every year, Storms & Floods kill Thousands and wipe away properties of Tens of Billions of Dollars.

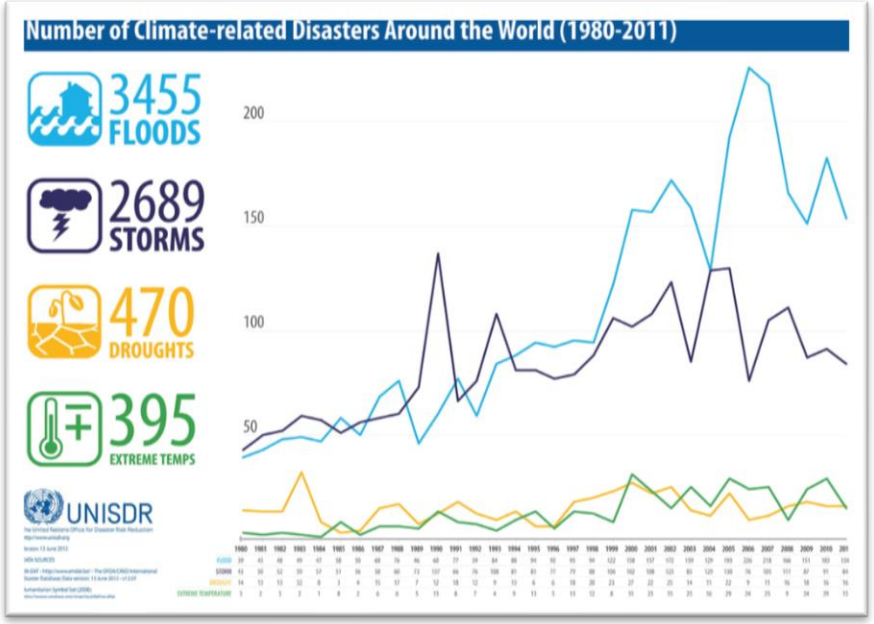
Myanmar

Macao

Bangladesh

Sri Lanka

Thailand



Sudden & Extreme Weather keeps Increasing under Climate Change.

Scales of Weather Forecasts

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Time Horizon

3 Month Forecast

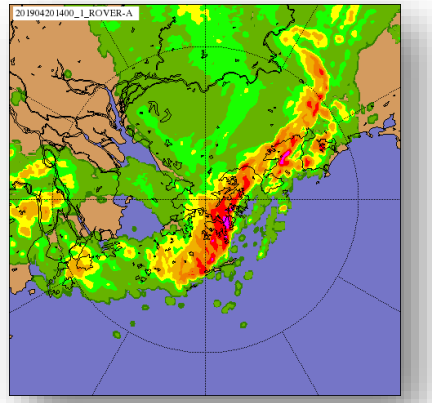
	Temperature Forecast	Rainfall Forecast
Jun – Aug 2019	Normal to above normal	Normal to above normal
Mar – May 2019	Normal to above normal	Normal to above normal
Dec 2018 – Feb 2019	Normal to above normal	Normal to above normal
Sep – Nov 2018	Normal to above normal	Normal to below normal

Roughly

1 - 9 Day Forecast

Generally

0 – 6 Hour Nowcast



Precisely

Nowcasting - Resolutions Matter

10 km

	Forecast	Nowcast
Range	1 – 9 Day	0 – 6 Hour
Interval	Hourly	6-Minutely

SWIRLS Nowcast System

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SWIRLS: Short-range Warning of Intense Rainstorms in Localized Systems

Observations

Satellites

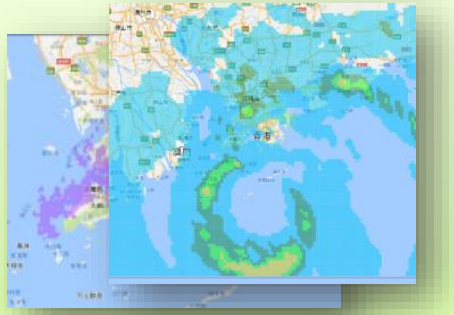
Radars

Rain Gauges

Lightning Detectors

Nowcast Modelling

Computers
80 TFLOPS CPU/GPU
1.5 TB RAM
960 TB Storage



Forecast Rainfall, Lightning, Hail & Gust

Products and Services

Weather Forecasters

Citizens

Government & Utilities

With SWIRLS Nowcasting

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Weather Forecasters

Issue Weather Warnings and Forecasts, which

- Save Lives
- Protect Properties

Citizens

Decide whether to:

- Seek Shelter?
- Bring Umbrellas?
- Cancel Hiking?
- Indoors or Outdoors?

Government & Utilities

Respond to:

- Improve Ecology of Wetland
- Enhance Productivity of Works
- Mobilize Staff in Advance
- Increase Power Supply Stability
- Suspend and Resume Operations

1. Simulate Radar Data from Satellite's using AI Neural Network in SWIRLS

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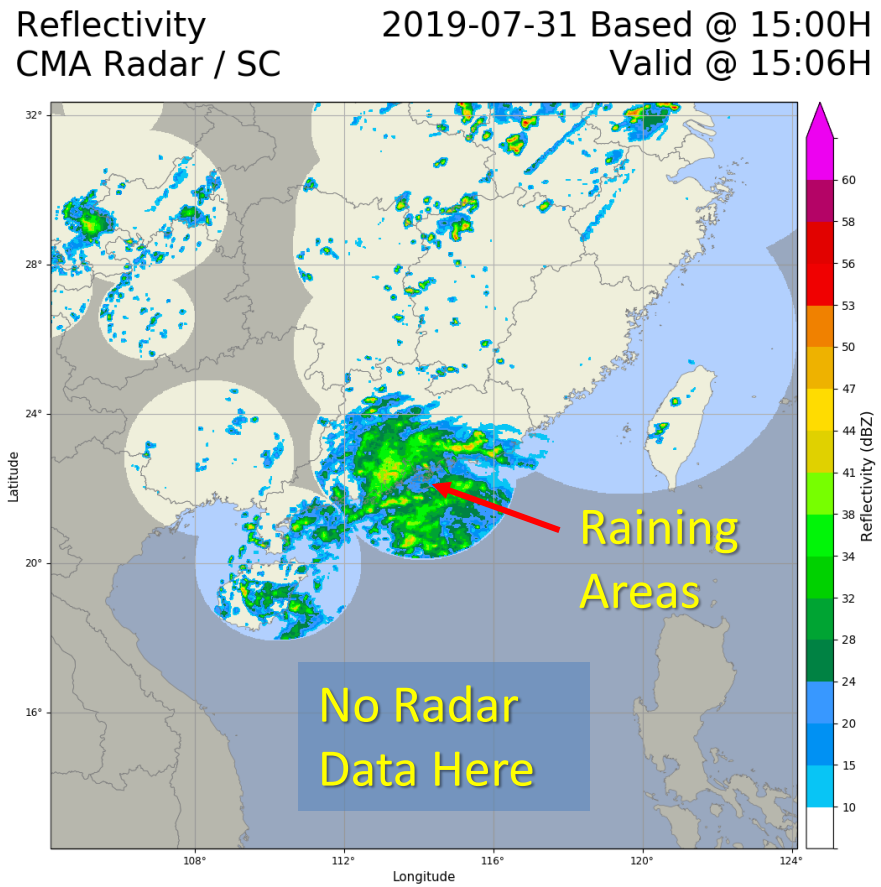
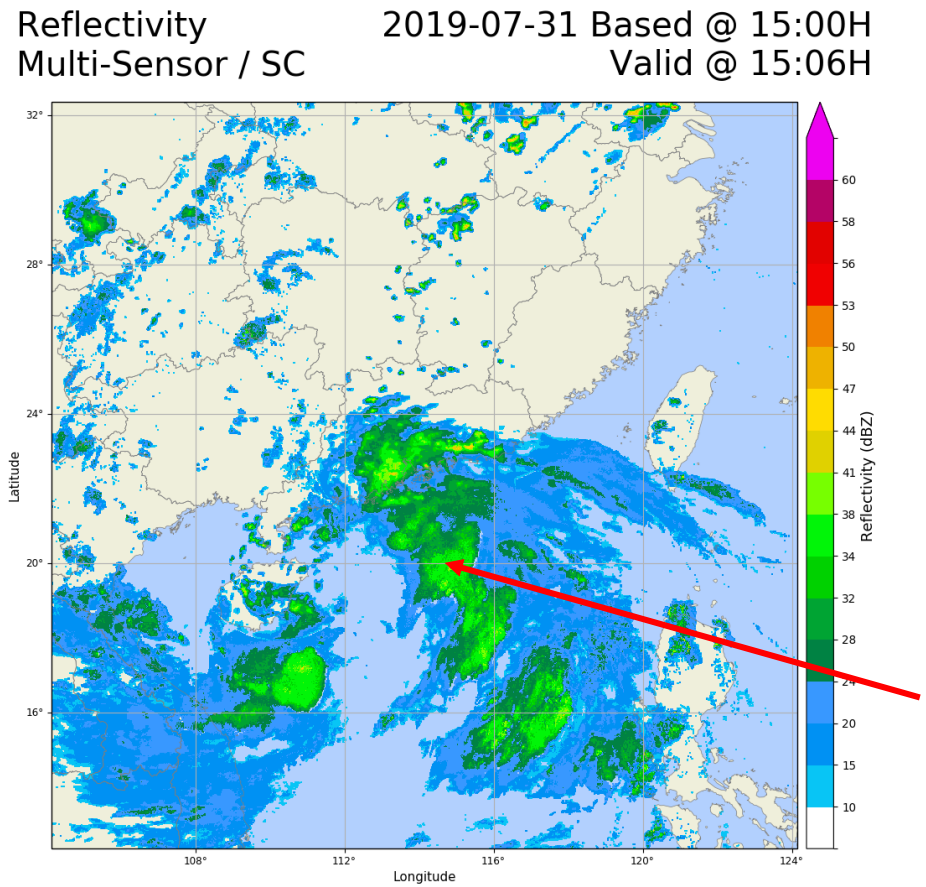


Original



With Our Neural Network

Raining Areas Far Away Simulated with Satellites' Data Using Our Neural Network

2. Nowcast with AI Computer Vision in SWIRLS

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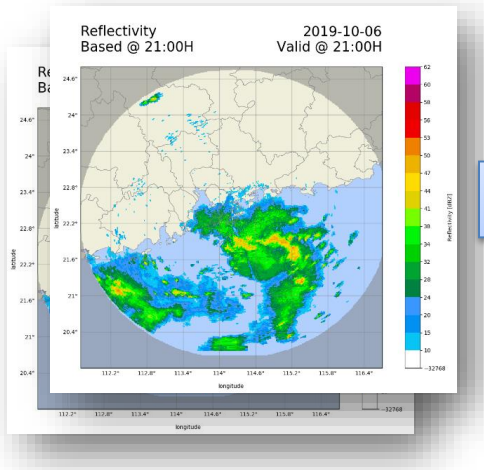
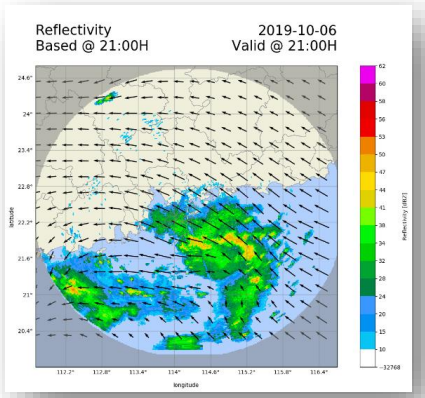
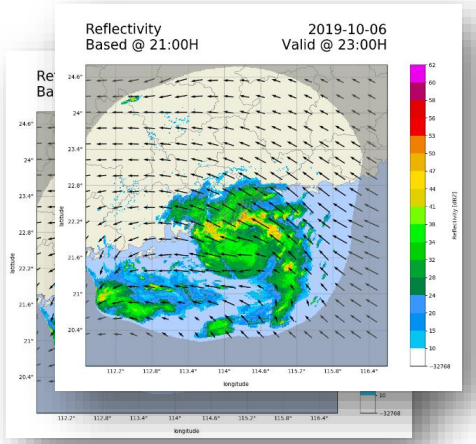


Actual Raining Areas



Calculate Speed & Direction of Raining Areas By **AI Computer Vision**



Forecast Raining Areas Using **GPU**

Precisely **Where**, **When** & **How Much** Rainfall

3. Next-Generation of SWIRLS AI Nowcast Enhanced Accuracy with Deep Learning

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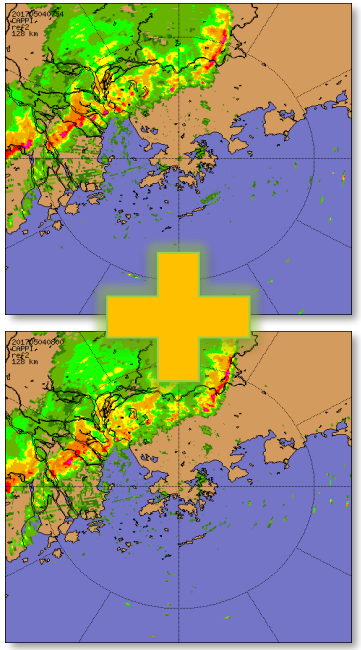
香港科技大學 THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY



Actual Radar Images

Deep Learning Nowcast

Big Data

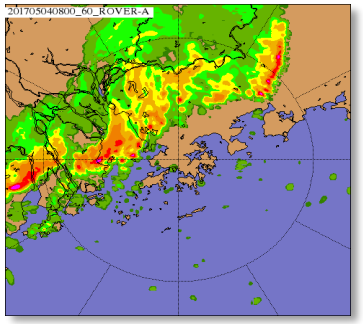
7 Years of Historical Data

140 Billions of Data Points

Trained AI Models to Predict Radar Images

Edge-Cutting Algorithms:

- Convolutional LSTM (Long-Short-Term-Memory)
- Trajectory GRU (Gated Recurrent Unit)



Forecast Radar Images

Pioneered "Deep Learning Nowcast"

Research Papers Related to SWIRLS Nowcast

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International / Regional Conference Paper

RR_1 **Development of Satellite Reflectivity Retrieval Technique for Tropical Cyclone Rainfall Nowcasting**

W.C. Woo[1], Y.Y. Ip[2], W.K. Wong[1], N.H. Chan[1]

Collaborative Development of the Community SWIRLS Nowcast System

Wang-chun Woo[1], Pak-him Kam[2], Ka-chun Shek[1], Ka-ho Ng[1]
The Hong Kong Observatory
Chinese University of Hong Kong

Location Specific Lightning Nowcast Service

CHAN Ngo-hin WOO Wang-chun
Hong Kong Observatory

小渦旋臨近預報系統熱帶氣旋模塊的

應用個案分析:颱風妮妲(1604)

Experimental Location Specific Probabilistic Rainfall Nowcast

EIGHTH INTERNATIONAL WORKSHOP ON TROPICAL CYCLONES

8.2: Challenges and Advances related to TC Rainfall Forecast

Rapporteur: WOO Wang-chun
Hong Kong Observatory
134A Nathan Road, Tsim Sha Tsui, Kowloon, Hong Kong, China.

An Automated System to Express Actual Rainfall, Thunderstorm and Gust as well as Forecast Rainfall in Everyday Language

WOO Wang-chun[1] YEUNG Hoi-lam[1] LEUNG Ming-tak[2]
[1]Hong Kong Observatory [2]The University of Hong Kong

Abstract

In 2013, the Hong Kong Observatory developed a system that automatically compiles rainfall related messages for forecasters' reference when preparing "Special Weather Tips", based on regional rainfall records and quantitative precipitation forecasts from the SWIRLS nowcasting system.

The system was optimised and expanded during 2014 – 2015 to also cover information on thunderstorms and induced gusts. The regionalization mechanism in the system was revamped to make the rainfall, thunderstorm and gust messages more precise and accurate within the user-defined word count limit. This article introduces the new features of the enhanced system, and briefly describes the direction of future development and applications.

Academic Journal Papers

Cited 1,300+ times

Convolutional LSTM Network: A Machine Learning Approach for Precipitation Nowcasting

Xingjian Shi Zhourong Chen Hao Wang Dit-Yan Yeung

Deep Learning for Precipitation Nowcasting: A Benchmark and A New Model

Xingjian Shi, Zhihan Gao, Leonard Lausen, Hao Wang, Dit-Yan Yeung
Department of Computer Science and Engineering
Hong Kong University of Science and Technology
{xshiab,zgaoag,lelausen,hwangaz,dyyeung}@cse.ust.hk

atmosphere MDPI

Article

Operational Application of Optical Flow Techniques to Radar-Based Rainfall Nowcasting

Wang-chun Woo * and Wai-kin Wong

Forecast Development Division, Hong Kong Observatory, Hong Kong 999077, China; wkwong@hko.gov.hk
* Correspondence: wcwoo@hko.gov.hk; Tel.: +852-2926-8453

May 2014 WOO ET AL. 111

AN ALGORITHM TO ENHANCE NOWCAST OF RAINFALL BROUGHT BY TROPICAL CYCLONES THROUGH SEPARATION OF MOTIONS

W.C. Woo[1], K.K. Li[2], Michael Bala[3]

[1]*Hong Kong Observatory, Hong Kong, China*
[2]*The Chinese University of Hong Kong, Hong Kong, China*
[3]*Philippine Atmospheric, Geophysical and Astronomical Services Administration, the Philippines*

ABSTRACT

The Hong Kong Observatory operates an in-house developed nowcasting system, namely "Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS)", to support the operation of rainstorm and severe weather warnings as well as to provide rainfall nowcast services for the public and for special users in Hong Kong. Aiming to enhancing its performance in nowcast of rainfall brought by tropical cyclones, a new radar echo tracking scheme that separates the motion of the spiraling rain bands from the overall movement of tropical cyclone has been developed. Back-testing with historical cases in the past ten years reveals that the new scheme is more capable of preserving tropical cyclone rain band structures and can enhance forecast skills.

Keywords: rainfall nowcast, quantitative precipitation forecast, tropical cyclone

SWIRLS Nowcast for Weather Forecasters

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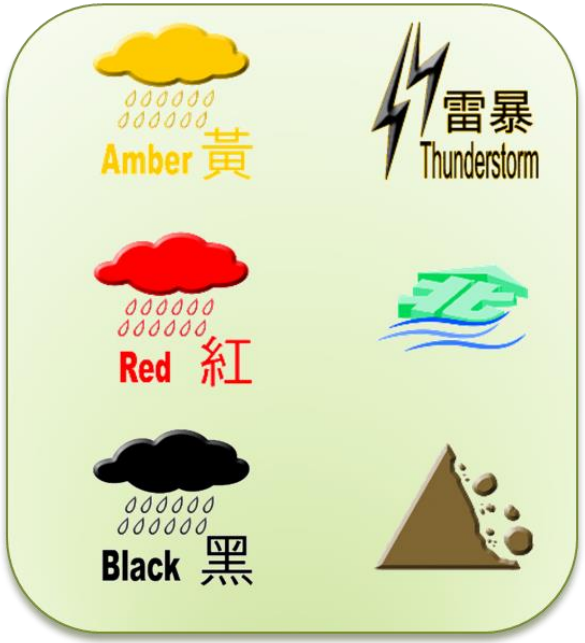
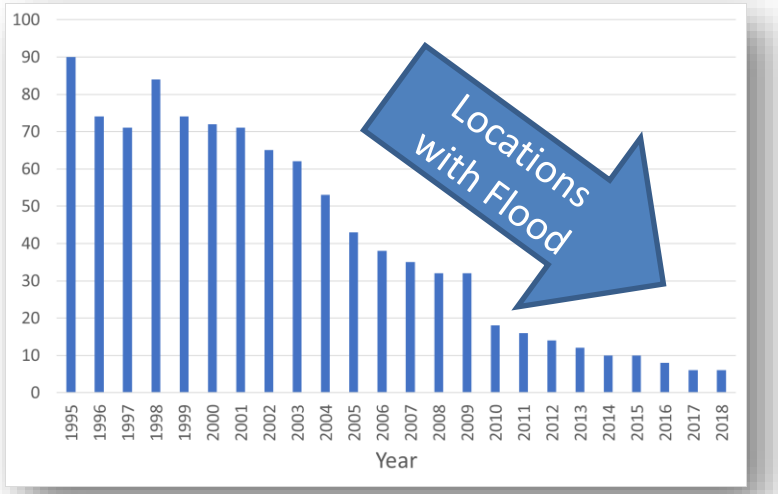
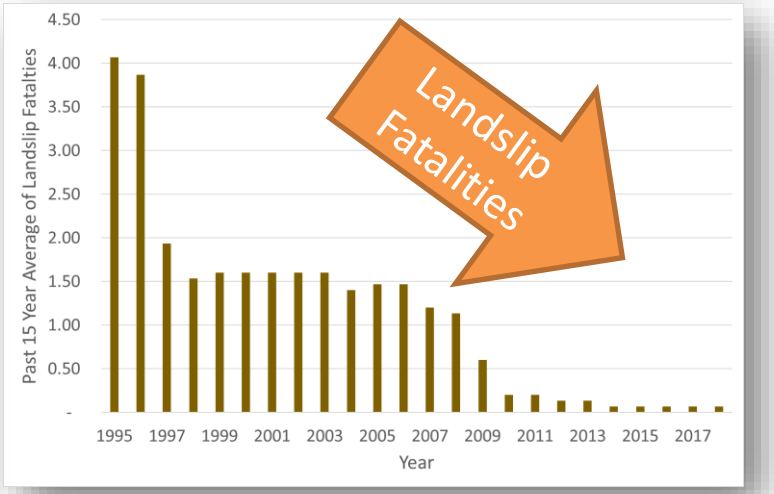


Guidance on **Rainstorm Warnings** are provided **Half an Hour in Advance**, reducing casualties and damages.

No. of **Floods and Landslides** in Hong Kong decreased over the years





SWIRLS Nowcast for Citizens

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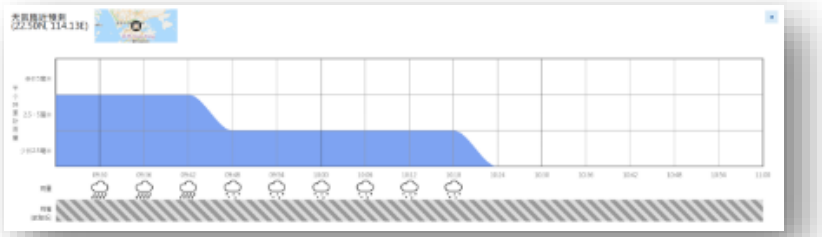
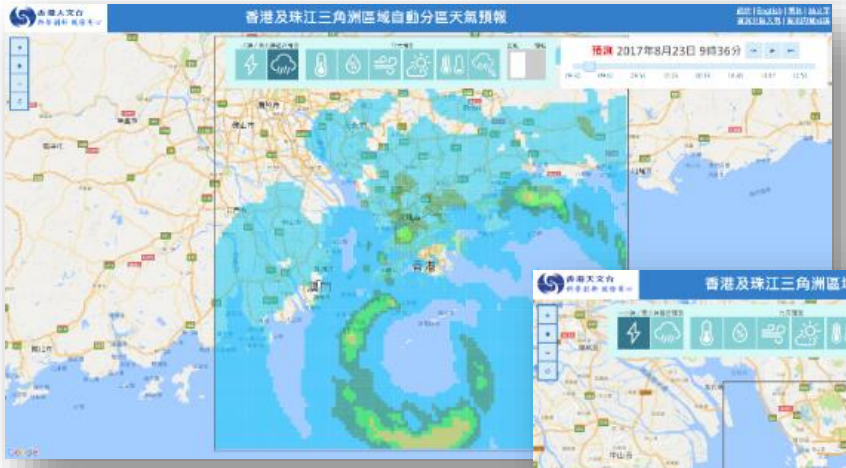
Rainfall/Lightning Nowcast On Mobile App

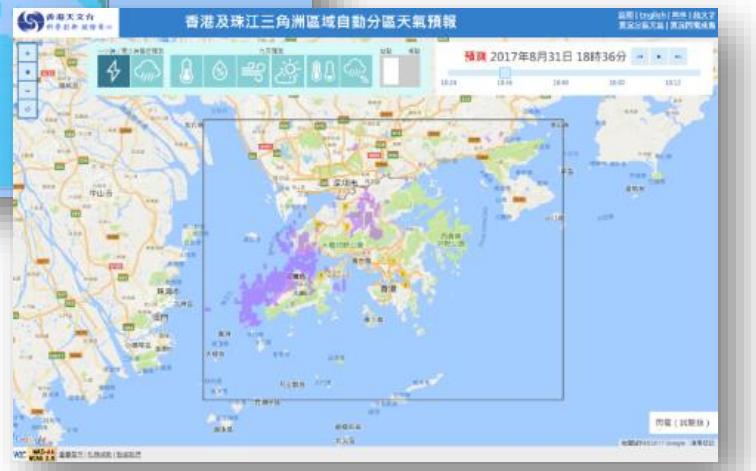
Over 1.5 million active users

Rainfall/Lighting Nowcast On Internet Website





Rainfall Nowcast



Lightning Nowcast

Over 10 billion visits in 2019

SWIRLS Rainfall Nowcast for Drainage Services Department

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Drainage Services Department
The Government of the Hong Kong Special Administrative Region

Drainage System in Shuen Wan Wetland

SWIRLS Nowcast
Rainfall & Warning

Rainy Mode

Sunny Mode

Prevent Flood

Preserve Wetland

Greatly Improves Wetland's Ecology

SWIRLS Rainfall Nowcast for Drainage Services Department

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HONG KONG OBSERVATORY

Drainage Services Department
The Government of the Hong Kong Special Administrative Region

Construction Works inside Kai Tak River

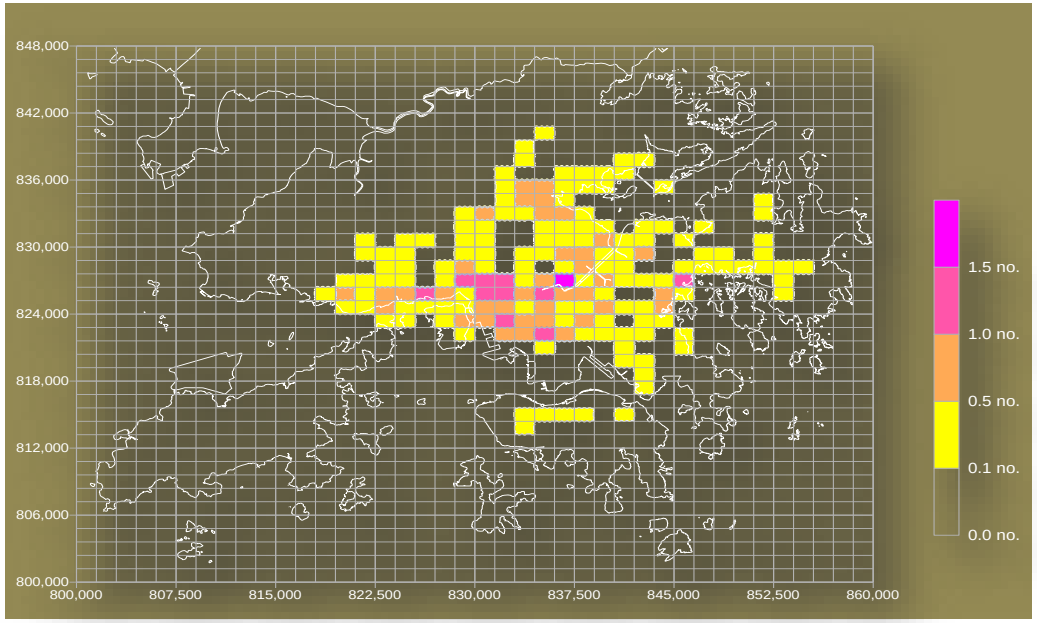
After adopting rainfall nowcast, workers can work until 2 hours before the arrival of rainstorms.

Enhances Productivity of Workers

SWIRLS Rainfall Nowcast for Geotechnical Engineering Office (GEO)

香港天文台 HONG KONG OBSERVATORY

CEDD 土木工程拓展署 Civil Engineering and Development Department



GEO's Landslip Model

Rainfall Nowcast are used for modelling Number and Locations of Landslides

Supports Decision on Landslip Warning
Enables Mobilization of Staff in Advance

SWIRLS Lightning Alerts for Power Company

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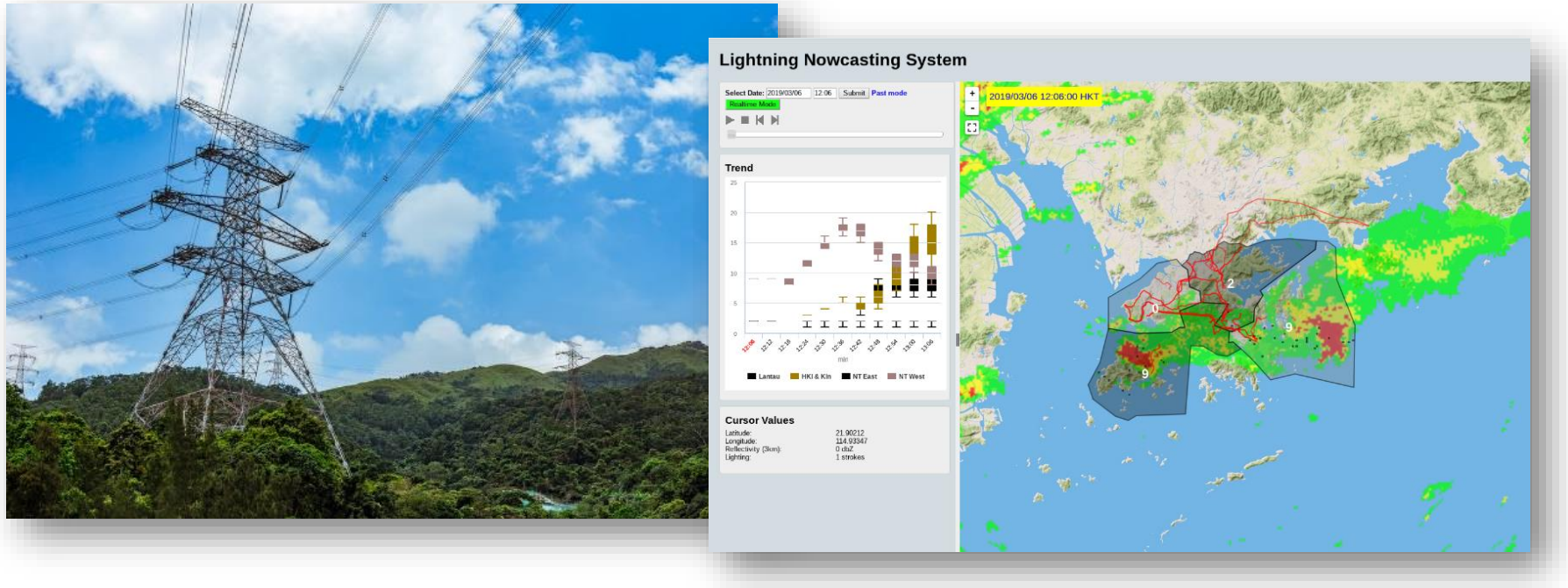
CLP 中電



Power Supply Reliability: 99.999%

Supports Decisions on Mobilization
Enables Rapid Resumption of Power

SWIRLS Lightning Alerts for Hong Kong International Airport

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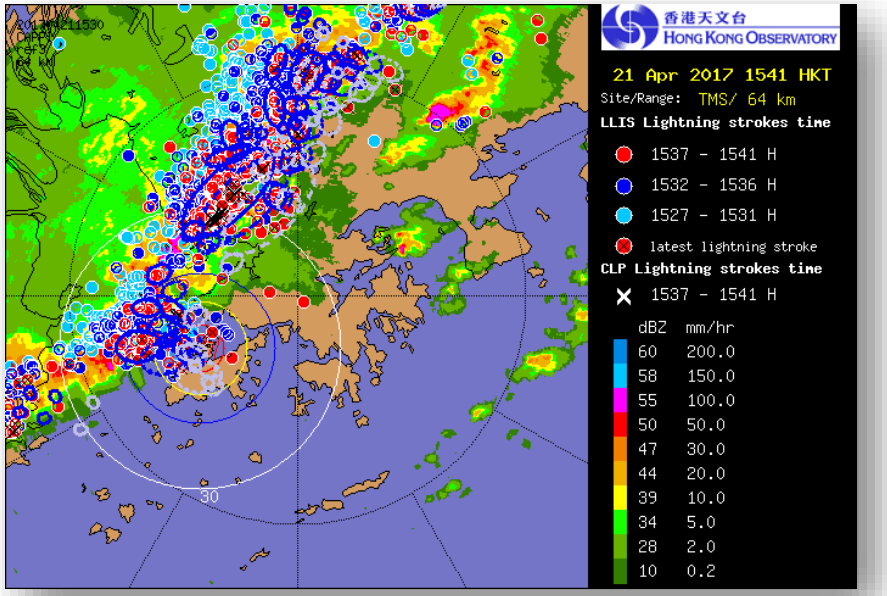
HONG KONG OBSERVATORY

香港機場管理局
AIRPORT AUTHORITY HONG KONG



Minimizes Risk of Lightning Strikes
Of Ground Staff in the Airport

SWIRLS Lightning Alerts for Theme Park, Golf Course & Cable Car

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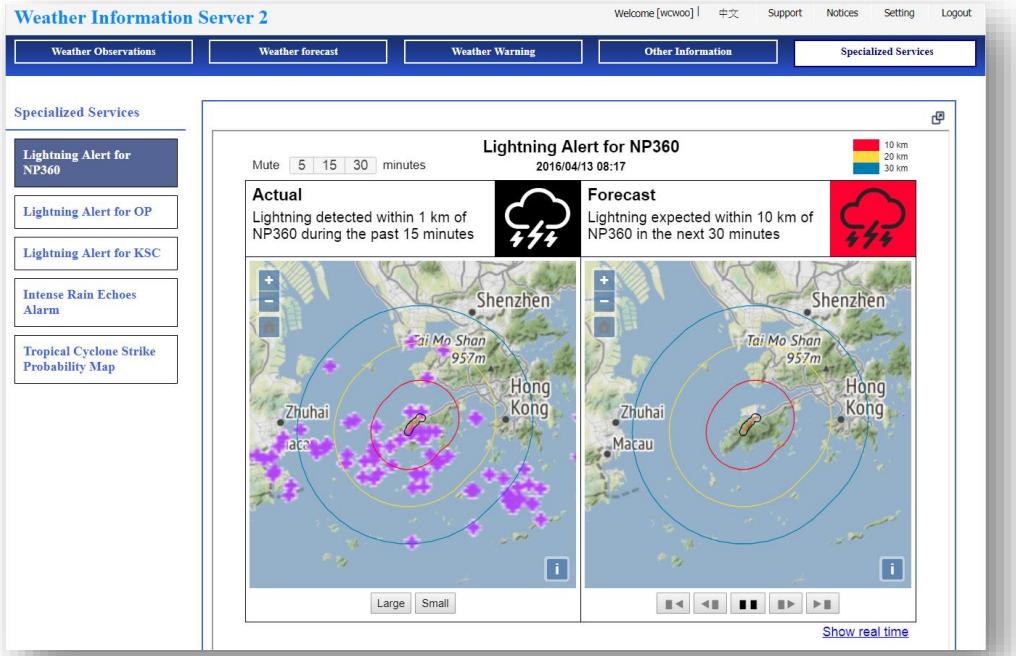

Enable Timely Suspension of Services Before Thunderstorms and Early Resumption After

Technology Transfer for Overseas Weather Services

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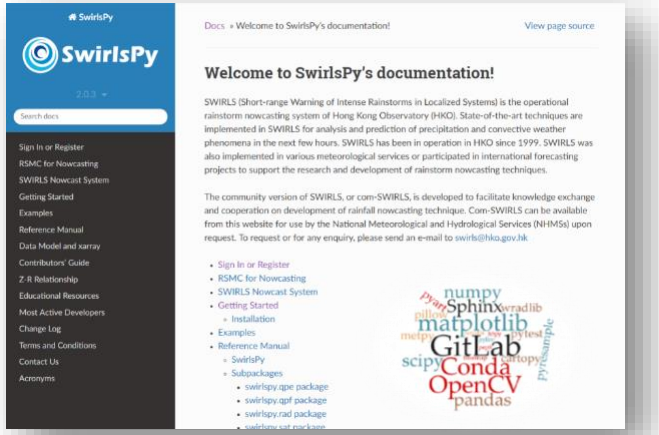
Easy to Install, Configure and Use



Community SWIRLS Platform For Developers

Overseas Weather Services

Weather Forecasters

Citizens

Government & Utilities

Community SWIRLS Nowcast System

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Transferred to 33 Countries/Regions

Asia Pacific

Australia
Bangladesh
China
Fiji
India
Indonesia
Japan
Korea
Laos
Macao
Malaysia
Myanmar
Philippines
Singapore
Sri Lanka
Thailand
Vietnam

Appreciation letters from …

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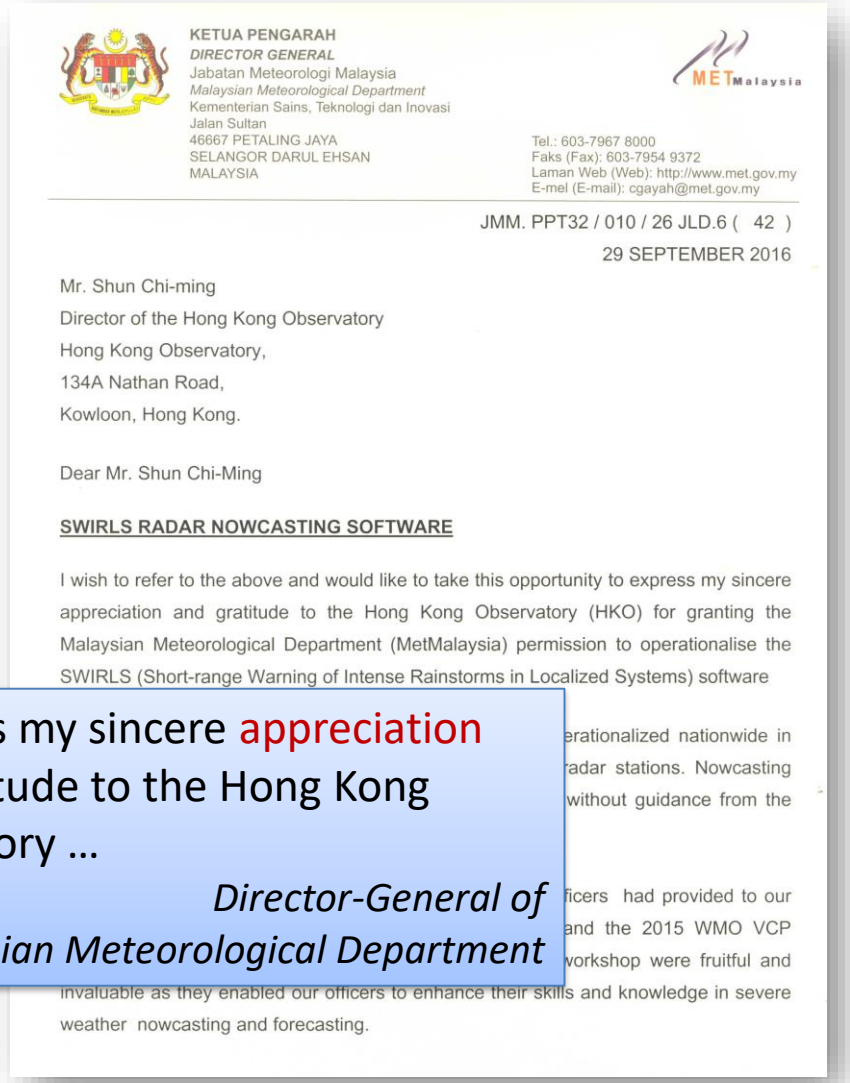
Malaysia



KETUA PENGARAH
DIRECTOR GENERAL
Jabatan Meteorologi Malaysia
Malaysian Meteorological Department
Kementerian Sains, Teknologi dan Inovasi
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46667 PETALING JAYA
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Laman Web (Web): http://www.met.gov.my
E-mel (E-mail): cgayah@met.gov.my

JMM. PPT32 / 010 / 26 JLD.6 (42)

29 SEPTEMBER 2016

Mr. Shun Chi-ming
Director of the Hong Kong Observatory
Hong Kong Observatory,
134A Nathan Road,
Kowloon, Hong Kong.

Dear Mr. Shun Chi-Ming

SWIRLS RADAR NOWCASTING SOFTWARE

I wish to refer to the above and would like to take this opportunity to express my sincere appreciation and gratitude to the Hong Kong Observatory (HKO) for granting the Malaysian Meteorological Department (MetMalaysia) permission to operationalise the SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) software

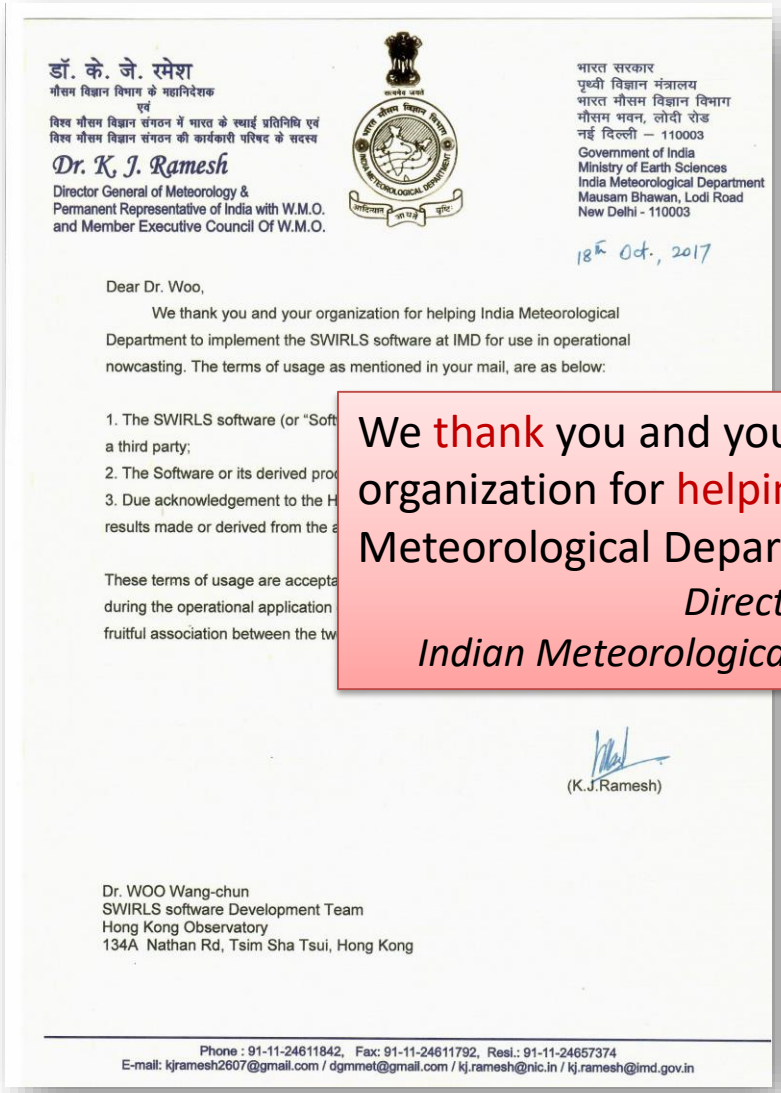
…erationalized nationwide in …adar stations. Nowcasting …without guidance from the

…ficers had provided to our …and the 2015 WMO VCP …workshop were fruitful and invaluable as they enabled our officers to enhance their skills and knowledge in severe weather nowcasting and forecasting.

… express my sincere appreciation and gratitude to the Hong Kong Observatory …

Director-General of Malaysian Meteorological Department

India



डॉ. के. जे. रमेश
मौसम विज्ञान विभाग के महानिदेशक
एवं
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि एवं
विश्व मौसम विज्ञान संगठन की कार्यकारी परिषद के सदस्य
Dr. K. J. Ramesh
Director General of Meteorology &
Permanent Representative of India with W.M.O.
and Member Executive Council Of W.M.O.

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम भवन, लोदी रोड
नई दिल्ली – 110003
Government of India
Ministry of Earth Sciences
India Meteorological Department
Mausam Bhawan, Lodi Road
New Delhi - 110003

18th Oct., 2017

Dear Dr. Woo,

We thank you and your organization for helping India Meteorological Department to implement the SWIRLS software at IMD for use in operational nowcasting. The terms of usage as mentioned in your mail, are as below:

1. The SWIRLS software (or "Soft…
a third party;
2. The Software or its derived pro…
3. Due acknowledgement to the H…
results made or derived from the …

These terms of usage are accepta…
during the operational application …
fruitful association between the tw…

(K.J.Ramesh)

Dr. WOO Wang-chun
SWIRLS software Development Team
Hong Kong Observatory
134A Nathan Rd, Tsim Sha Tsui, Hong Kong

Phone : 91-11-24611842, Fax: 91-11-24611792, Resi.: 91-11-24657374
E-mail: kjramesh2607@gmail.com / dgmmet@gmail.com / kj.ramesh@nic.in / kj.ramesh@imd.gov.in

We thank you and your organization for helping India Meteorological Department …

Director-General of Indian Meteorological Department

香港天文台
HONG KONG OBSERVATORY

臨近預報區域專業氣象中心
RSMC for Nowcasting

Designated as Regional Centre for Nowcasting by World Meteorological Organization (WMO), a United Nations Agency

UNITED NATIONS

WORLD METEOROLOGICAL ORGANIZATION

WMO is an UN Organization, like WTO, WHO etc.

In Recognition of our Outstanding Technology and Contributions, HKO has been designated by UN/WMO as a Regional Centre for Nowcasting. Opening inaugurated by HKO's Director (left) and Secretary-General of UN/WMO (right)

Awards

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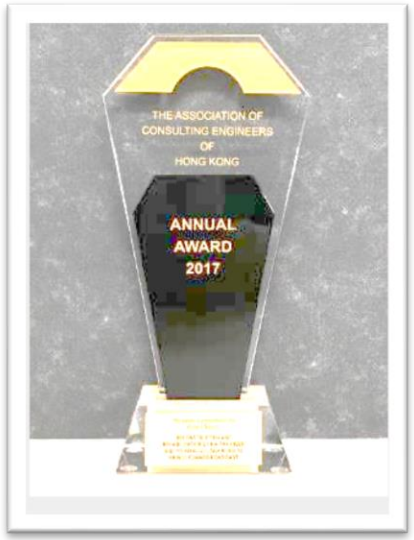

Annual Award of The Association of Consulting Engineers of Hong Kong 2017

Smart Business Grand Award
Smart Business (Solution for Business and Public Sector Enterprise) Gold Award
Hong Kong ICT Awards 2019

Winner Awards at the 19th Asia Pacific Information and Communications Technology Alliance (APICTA) Awards
Public Sector & Government category – Gov't & Citizen Services
Technology category – Artificial Intelligence
Ha Long Bay, Nov 2019

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SWIRLS IN HONG KONG

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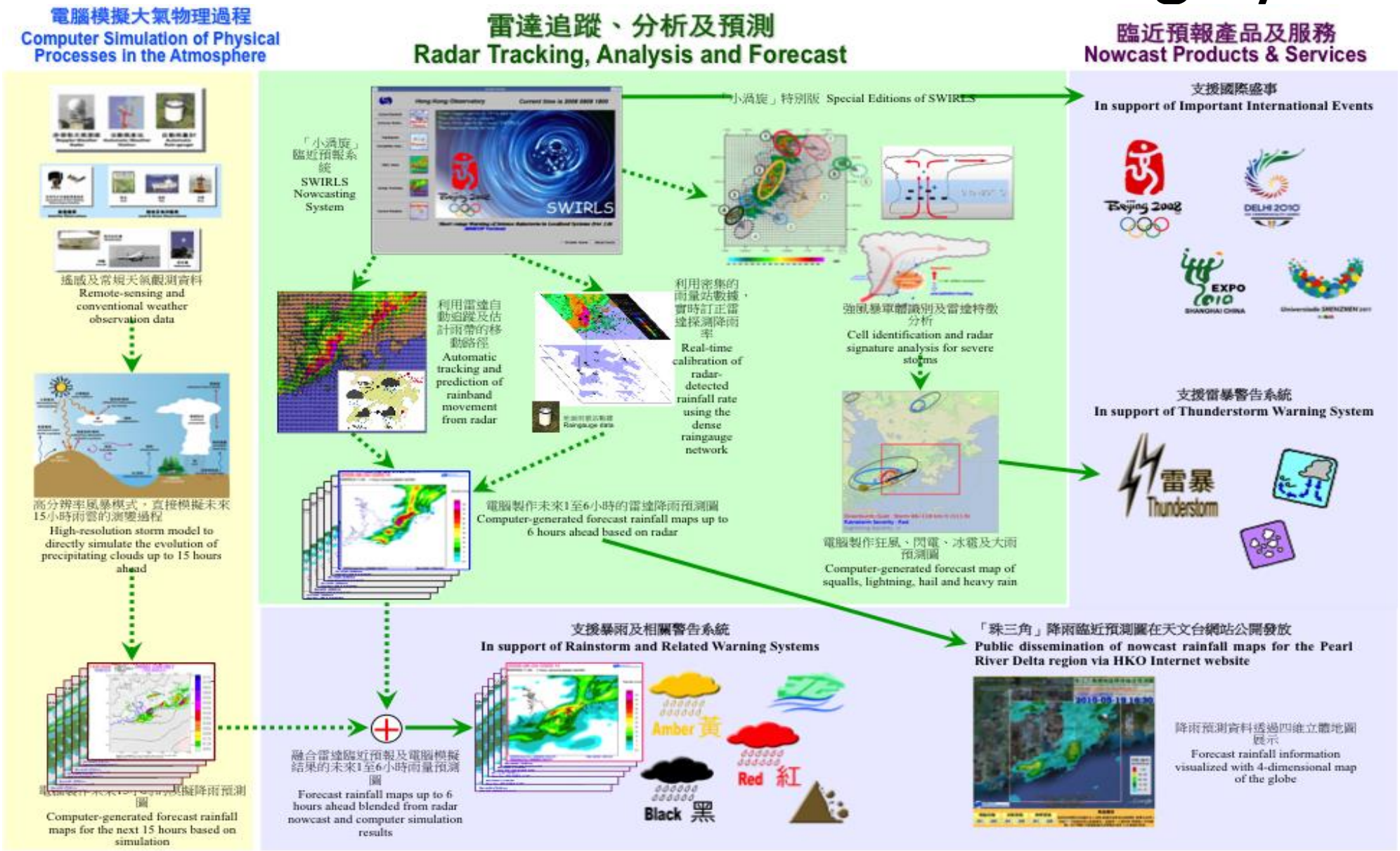
HONG KONG OBSERVATORY

SWIRLS – HKO Rainstorm Nowcasting System



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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

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SWIRLS' Core

香港天文台
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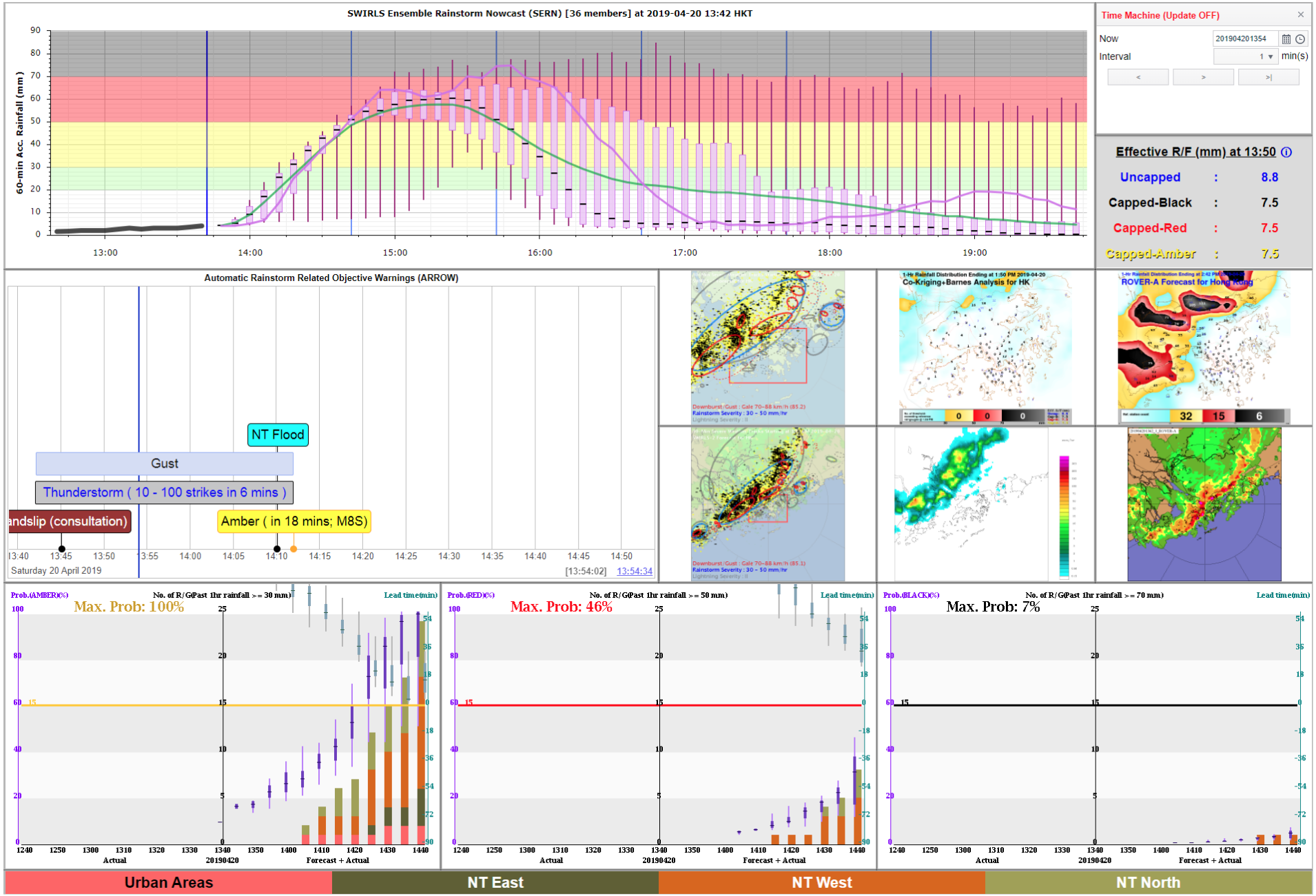
An integrated support on decision making (alerts, warning, consultation with government departments) during heavy rain situation



QPE – Quantitative Precipitation Estimation

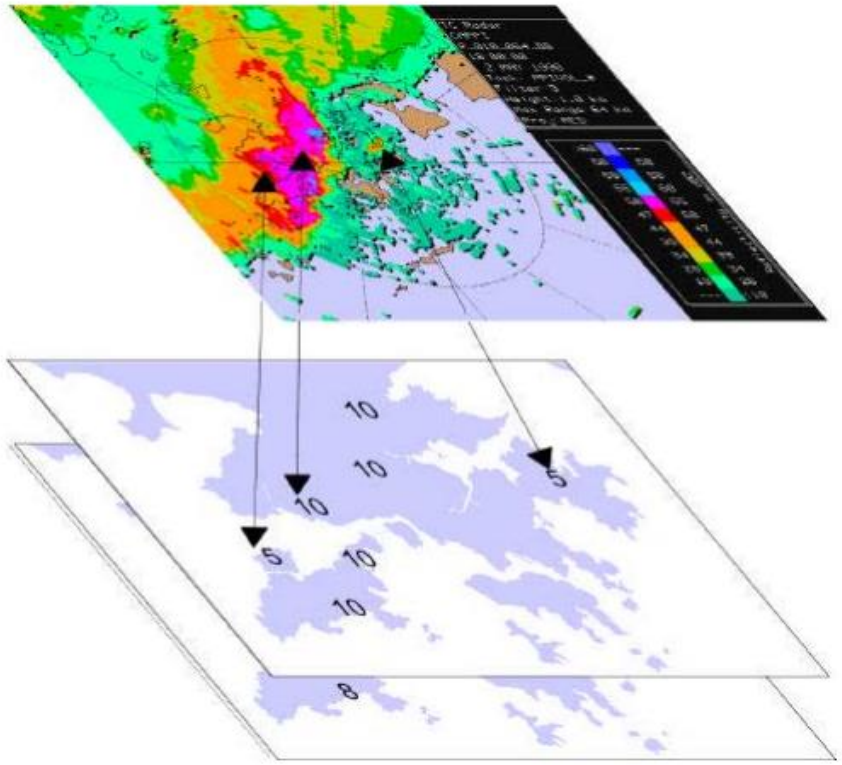
- Schematic diagram showing the calibration of radar reflectivity using real-time raingauge measurement.

- Z-R relation for converting reflectivity to rainfall rate

$$Z = aR^b$$

$$dBZ_i = b\ dBG_i + 10log(a)$$

- Gridded rainfall analysis computed by Barnes analysis or co-kriging algorithm



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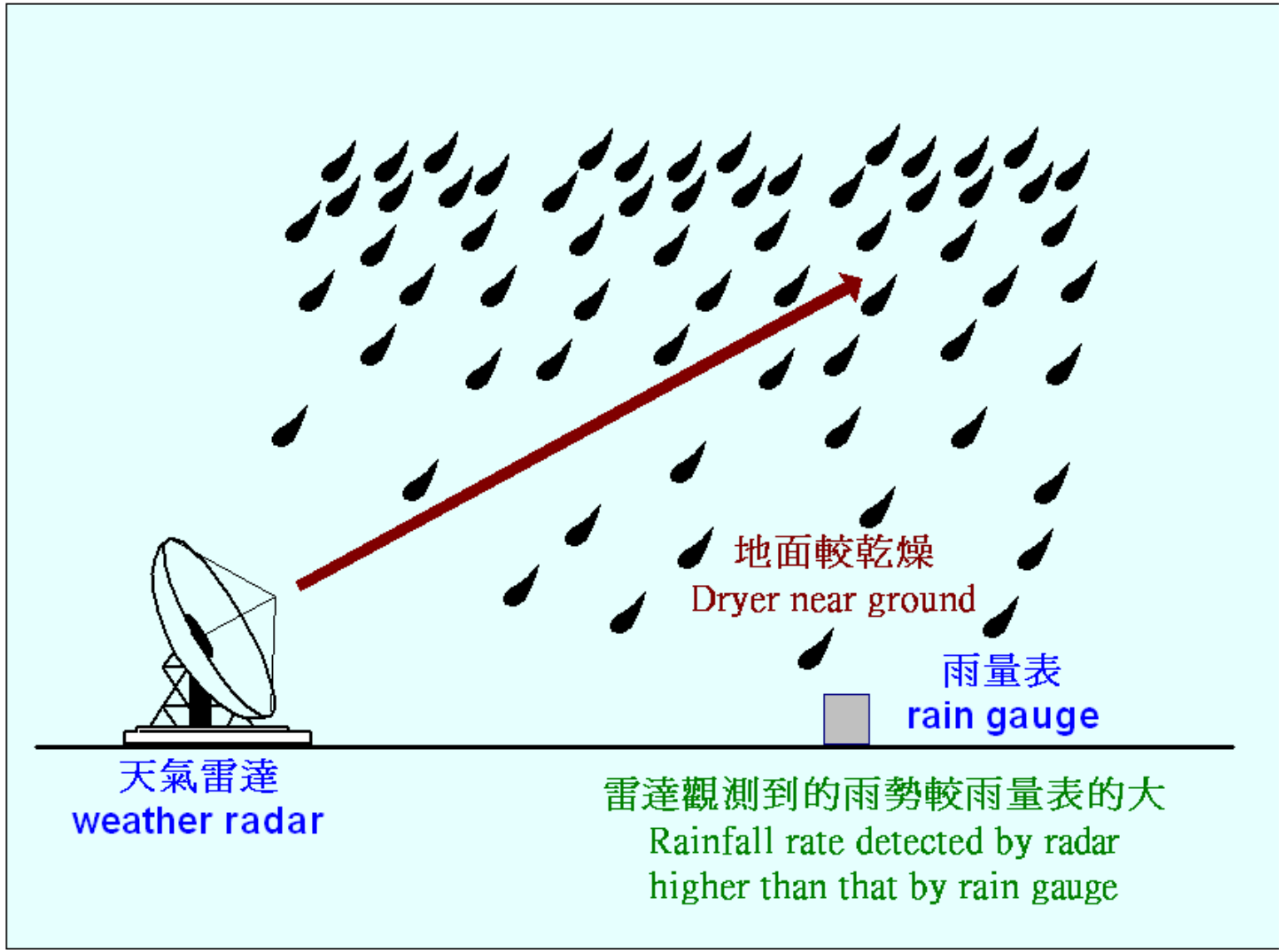
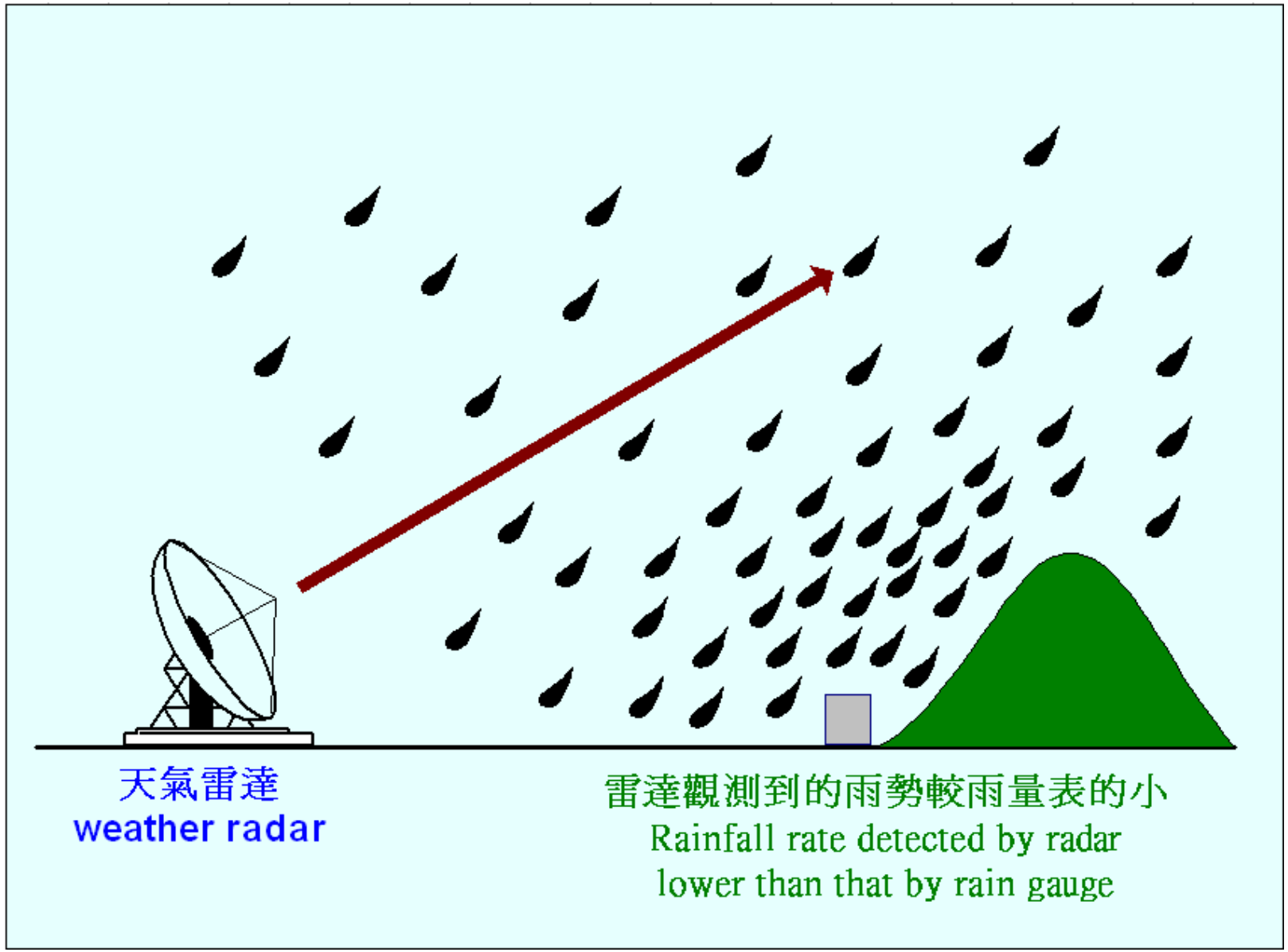
Limitations of Radar Measurements (1)

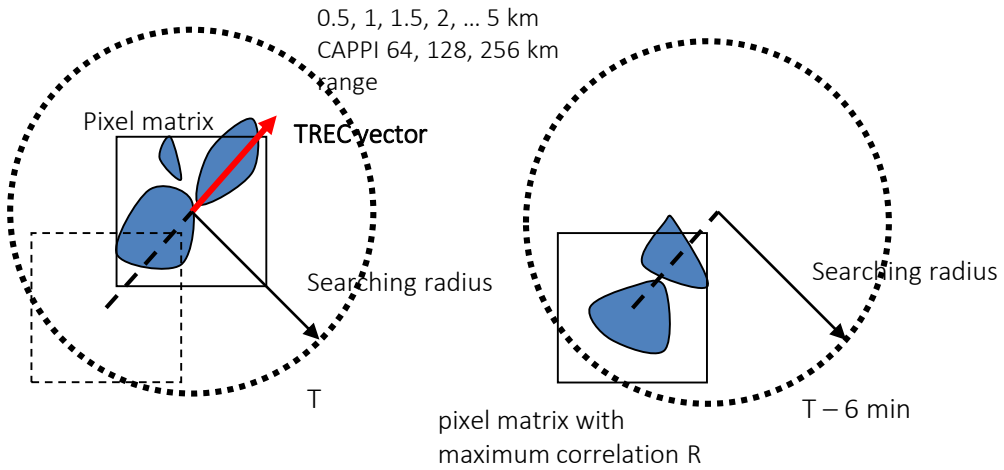


Limitations of Radar Measurements (1)



Radar Nowcasting – Echo Tracking

- 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

ROVER – Real-time Optical-flow by Variational method for Echoes of Radar

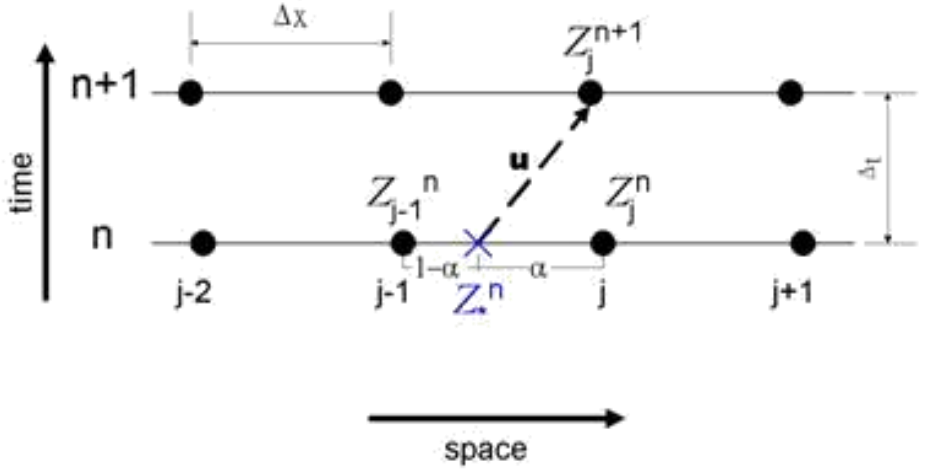
Given I(x,y,t) the image brightness at point (x,y) at time t and the brightness is constant when pattern moves, the echo motion components u(x,y) and v(x,y) can be retrieved via minimization of the cost function:

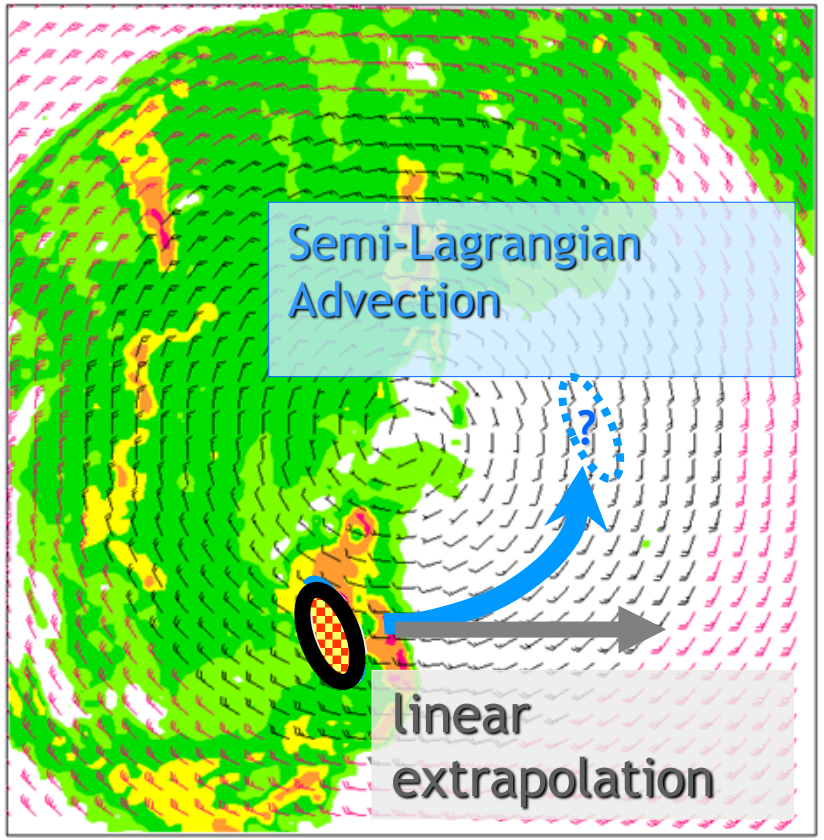
$$J = \iint \left[\frac{\partial I}{\partial t} + u \frac{\partial I}{\partial x} + v \frac{\partial I}{\partial y} \right]^2 dxdy$$

QPF - Forecast by Extrapolation

- Semi-Lagrangian Advection
  - Robert scheme (3 iterations to find origin point)
  - Bi-cubic interpolation
  - Flux limiter (local max, min constraint)
  - One-way nesting

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

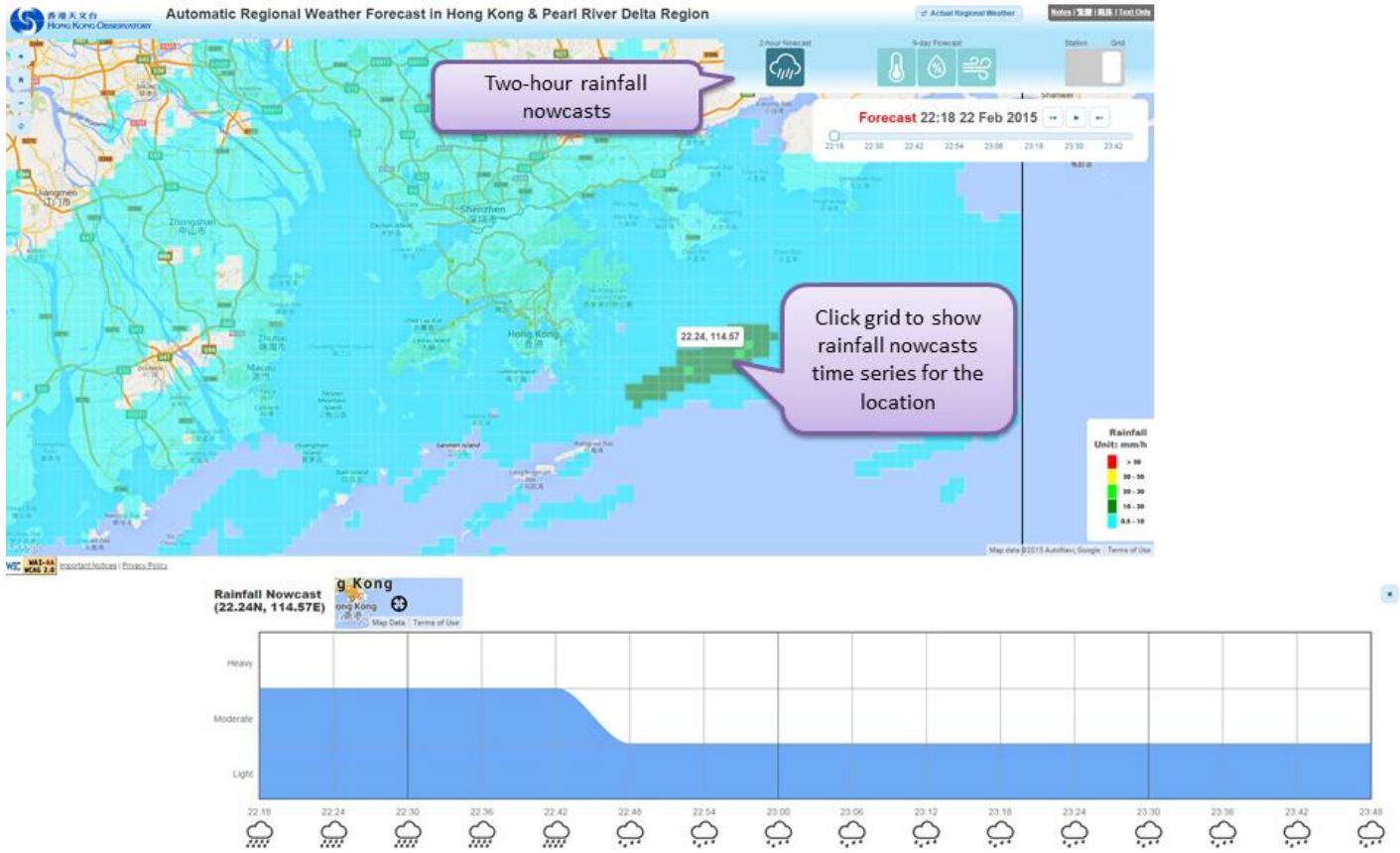




QPF (Quantitative Precipitation Forecast) For Public Weather Services

HKO Automatic Regional Weather Forecast

http://maps.weather.gov.hk/ocf/



"MyObservatory" mobile app on iOS and Android

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SWIRLS Nowcast Products to Public

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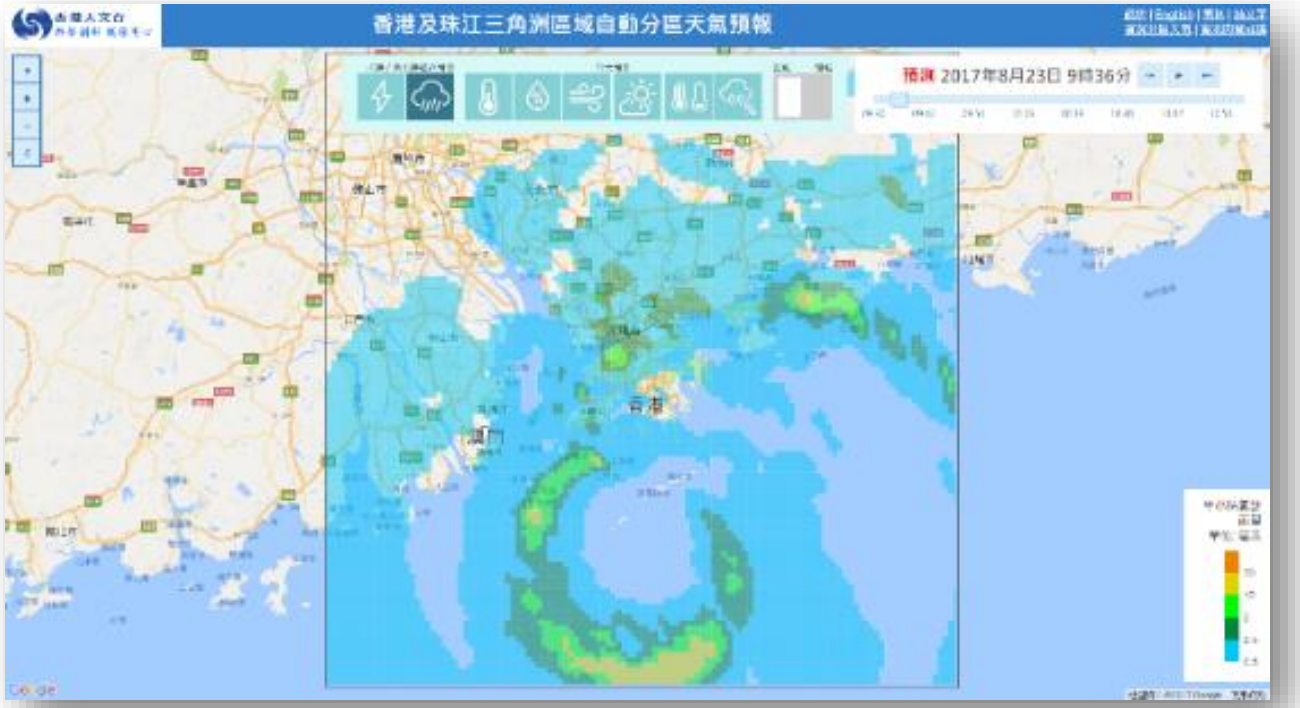
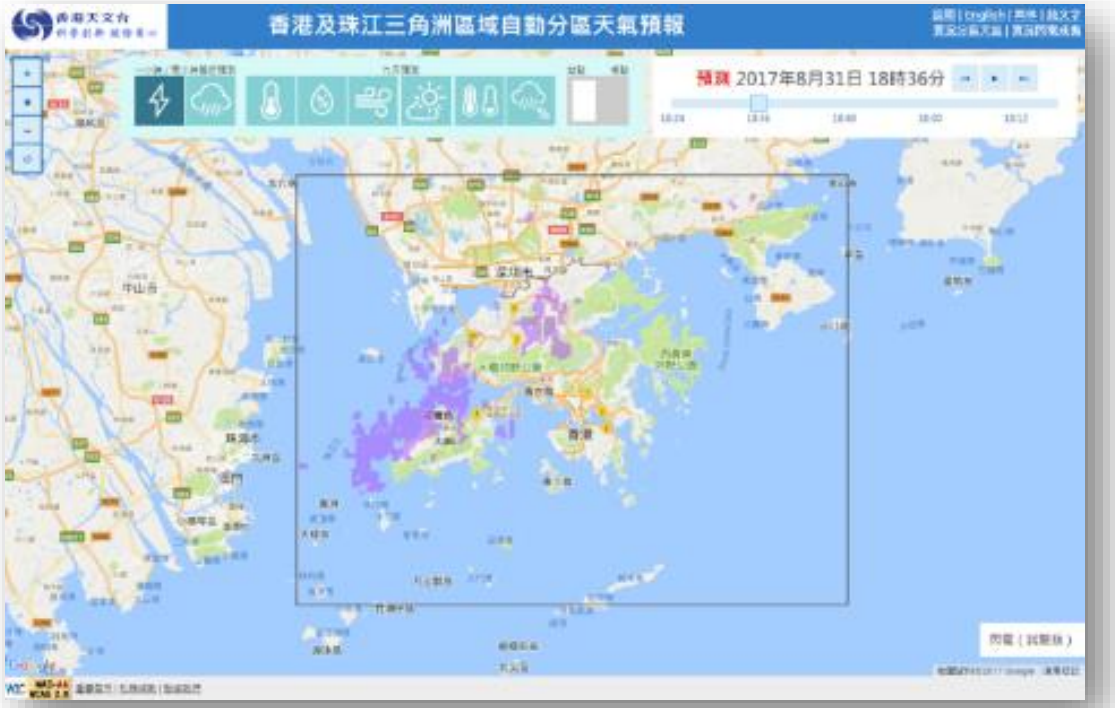
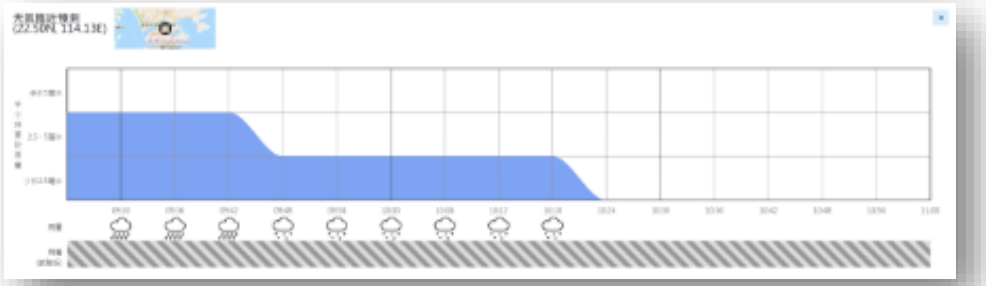
Rainfall and Lightning Nowcast

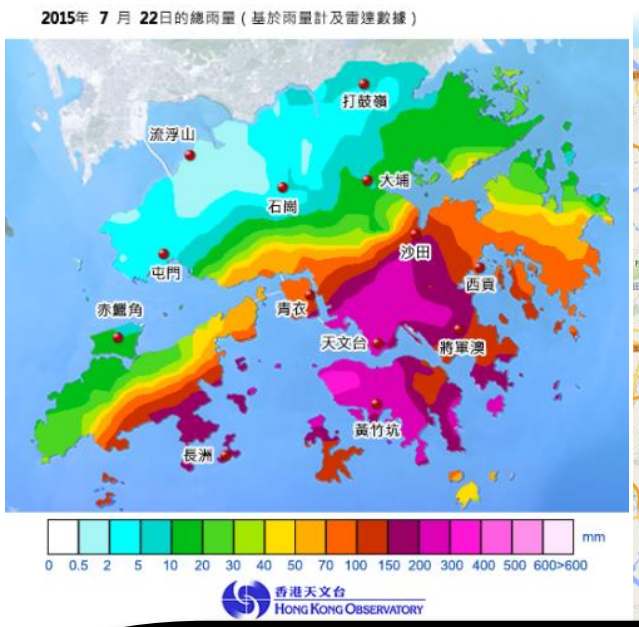






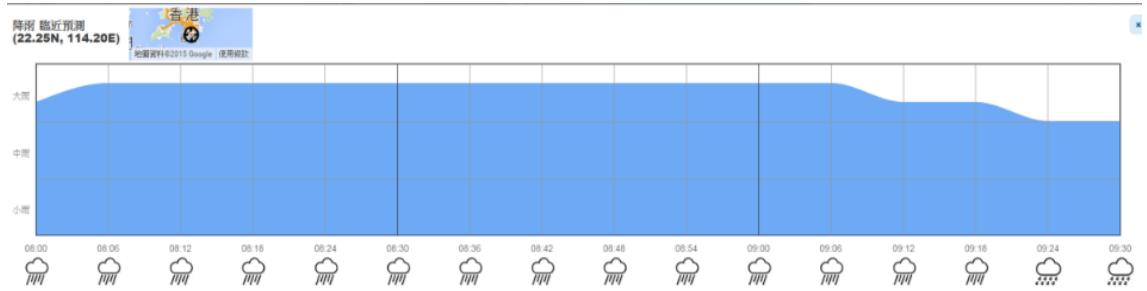
Seamless Integration of Rainfall Nowcast with Automatic Site-specific Weather Forecast

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



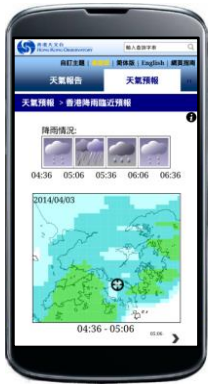
Rainfall nowcast for the next 2 hours

Click for the time series of the nowcast rainfall intensity



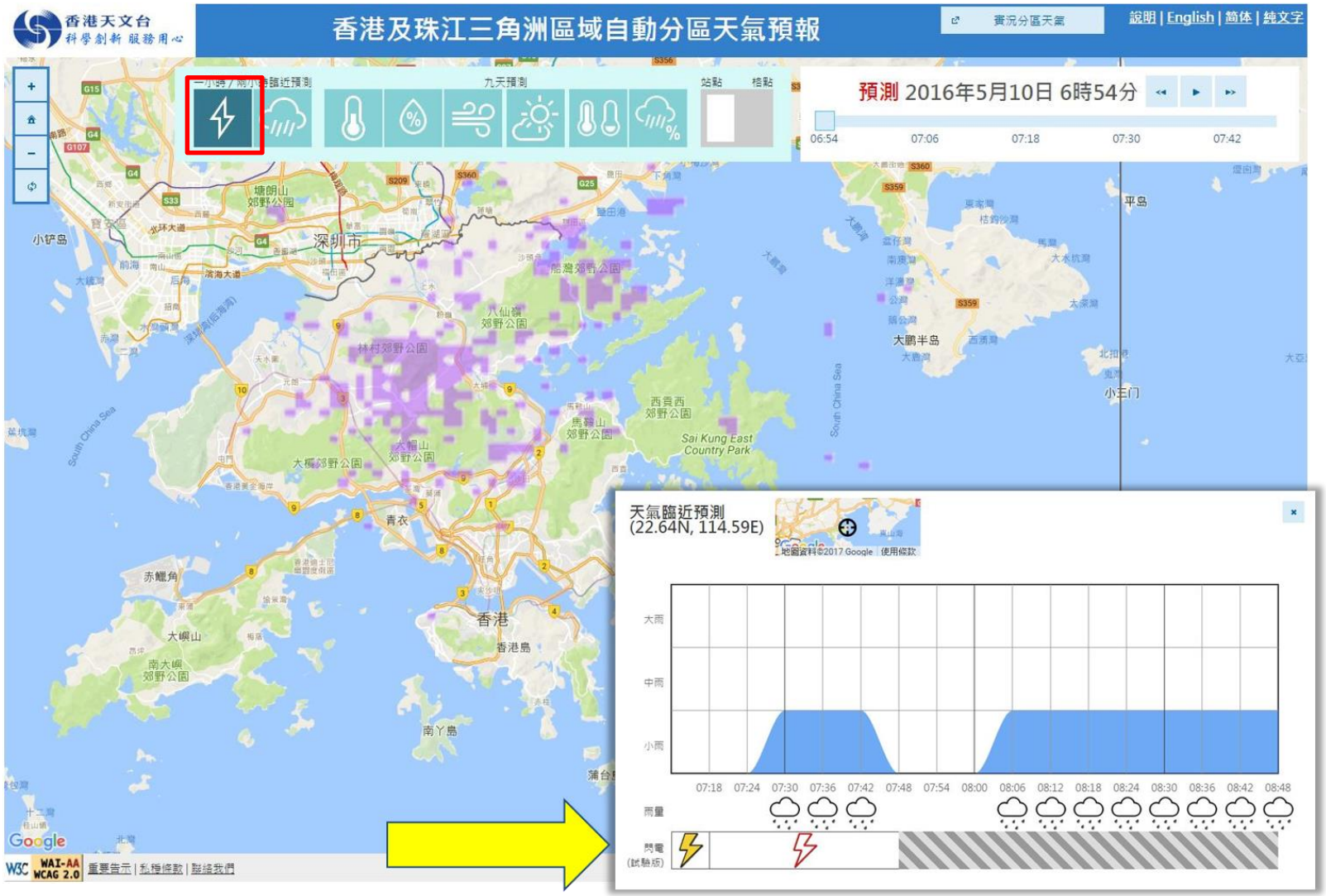
2015 年 7 月 22 日，天文台發出黃色暴雨警告接近 12 小時，而山泥傾瀉警告亦生效超過 6 小時。強降雨區在早上一段長時間幾乎停留在香港南部。

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



Lightning Nowcast in Automatic Regional Weather Forecast (ARWF) website

http://maps.weather.gov.hk/ocf/



Lightning within 10 km in the first 30-minute period

Lightning within 15 km in the first 30-minute period

Lightning within 10 km in the second 30-minute period

Lightning within 15 km in the second 30-minute period

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Location-specific Rainfall and Lightning Nowcasts

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Severe Weather Nowcast in SWIRLS

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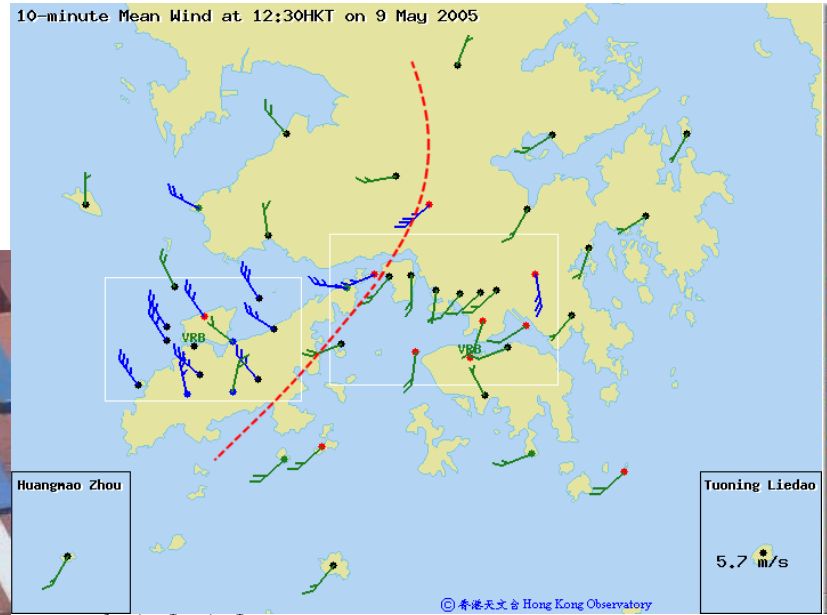
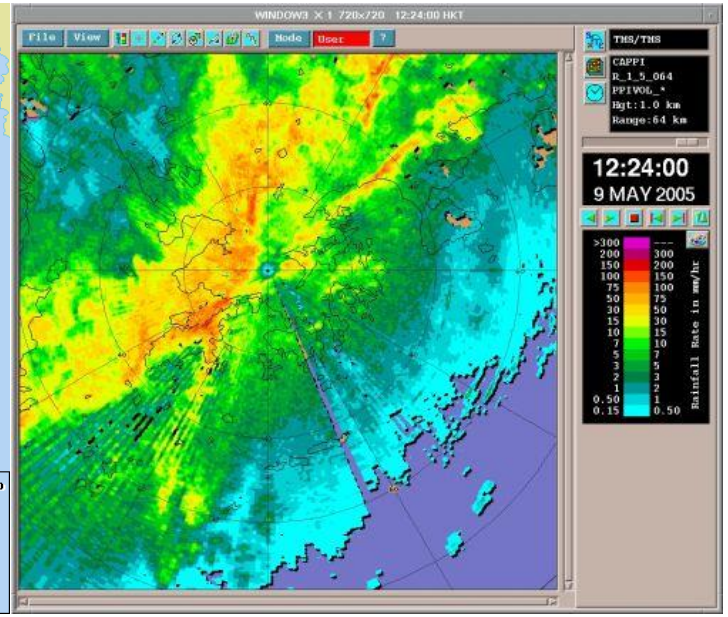
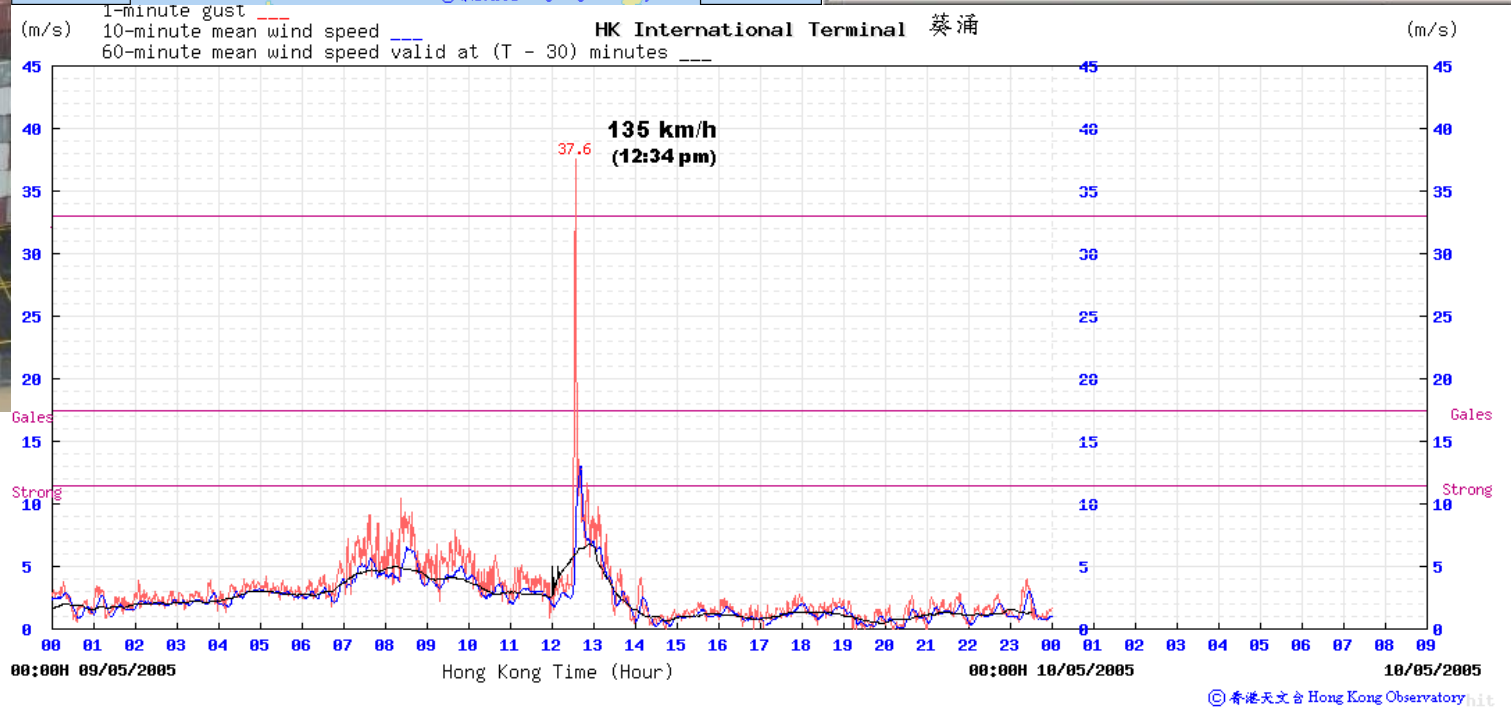
Strong gusts associated with thunderstorms blew down stacks of containers on 9 May 2005







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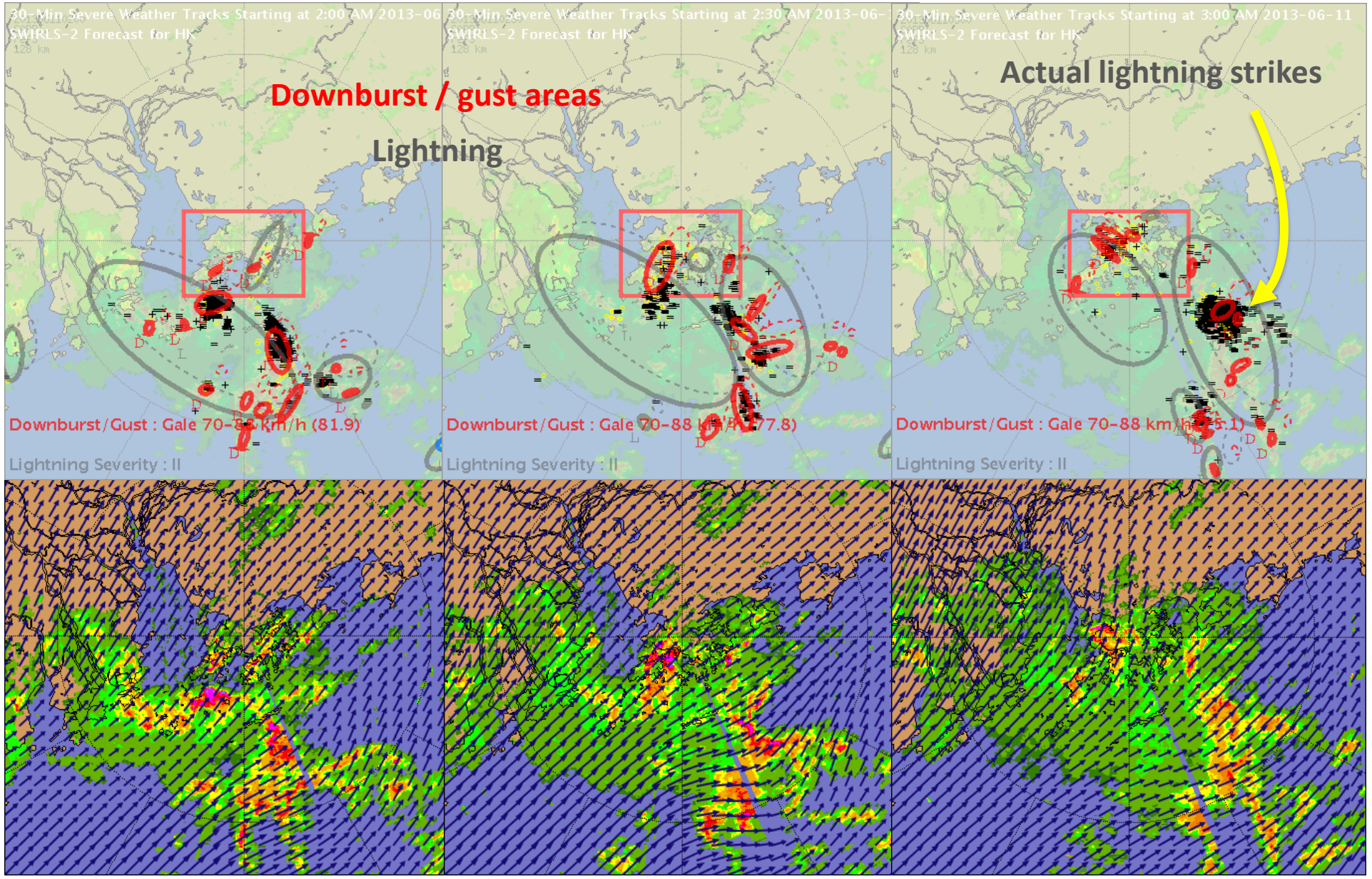
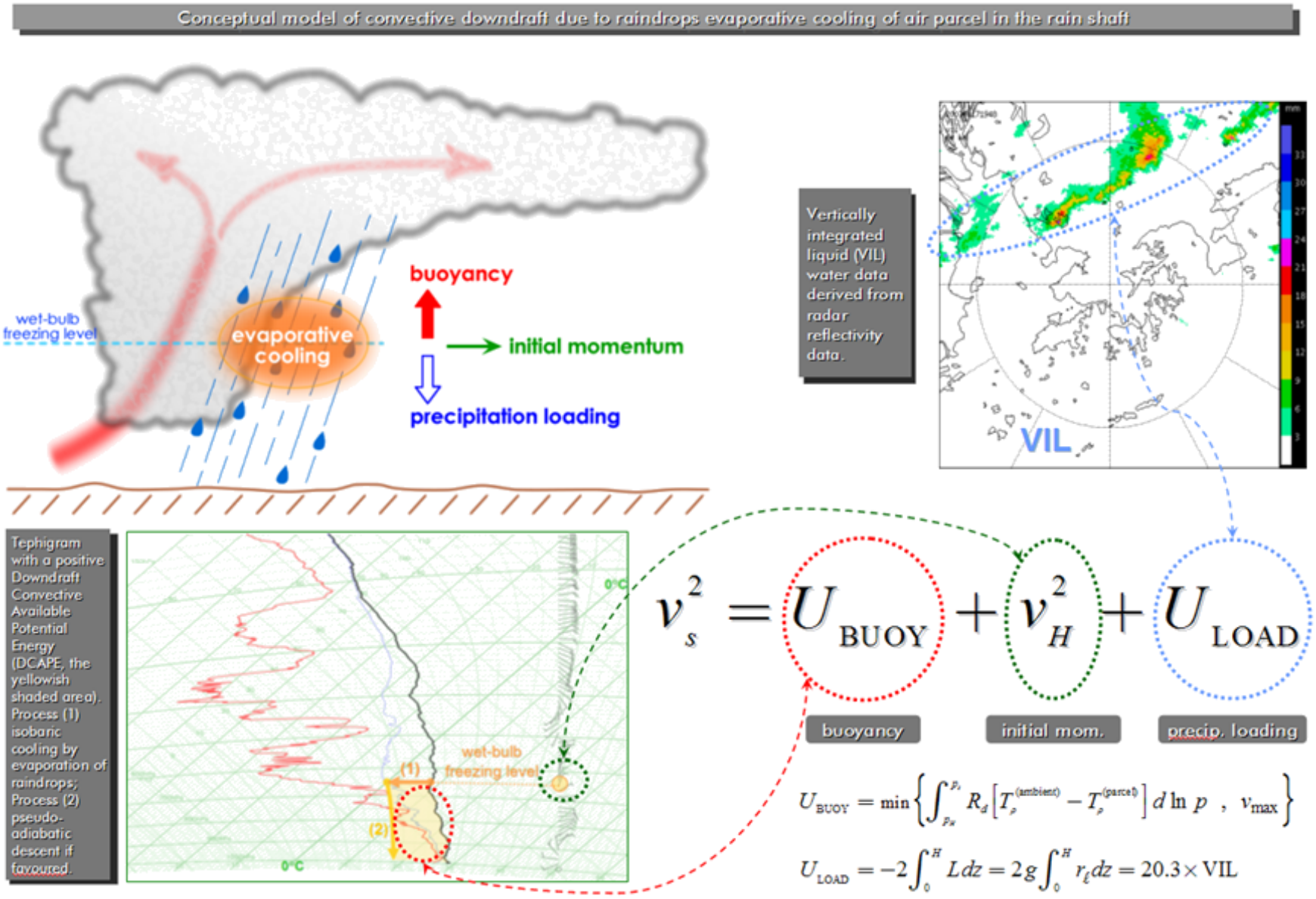
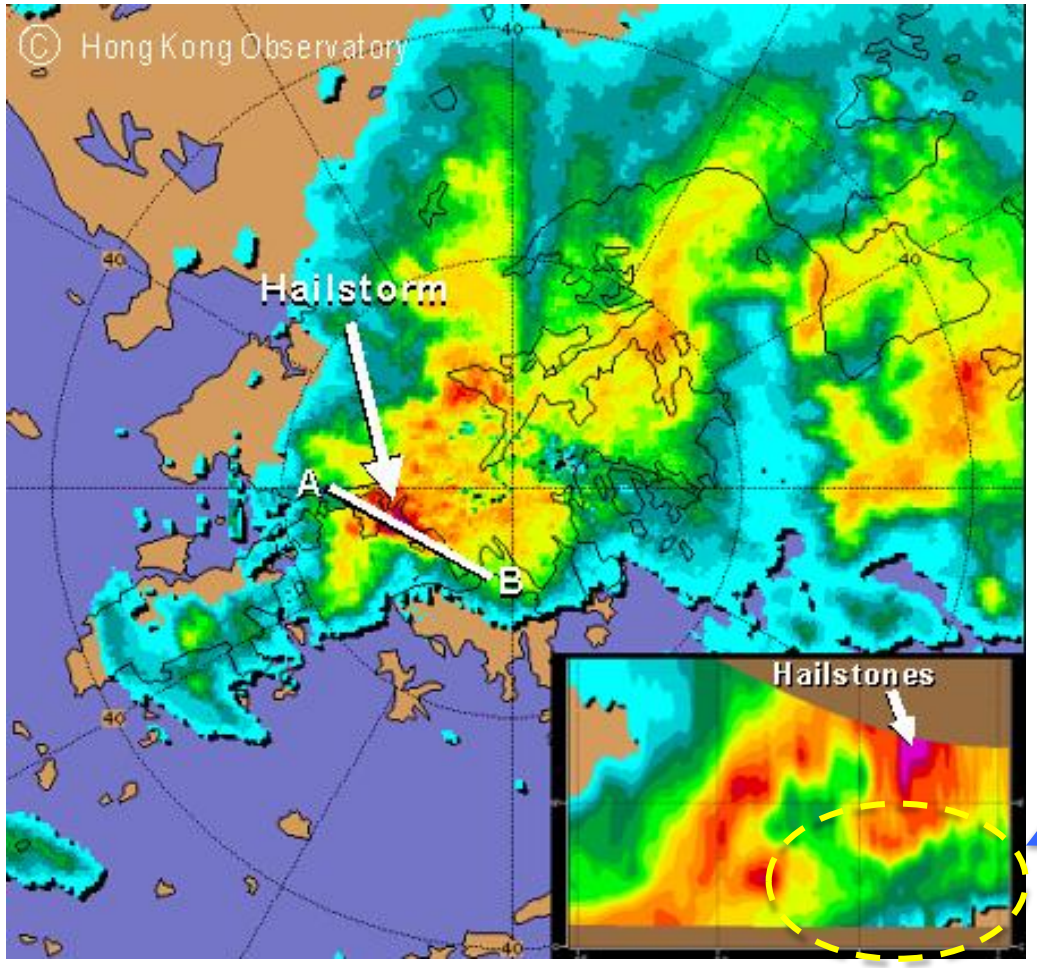
Severe Weather Nowcast



Conceptual Model of Downburst



Hail

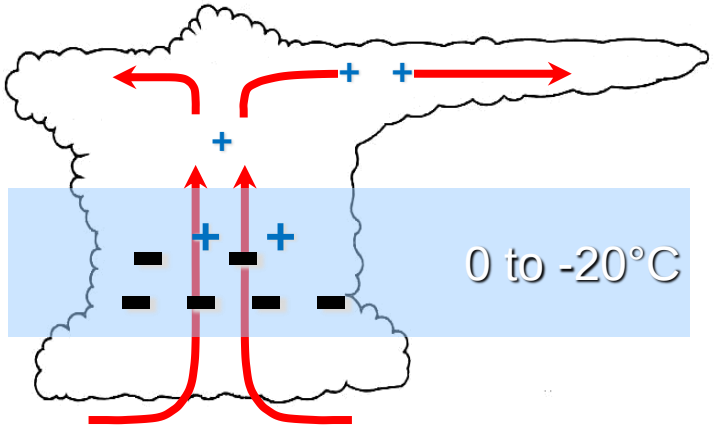


60-dBZ TOPS > 3 km

0-2km VIL < 5 mm

Lightning Nowcast

- +/- ve charges carried by ice and graupel respectively



(a) charge separated vertically by updraft

(b) physics reflected in radar observations:

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	⇑	*	
–10 to –20°C	⇑	*		⇑⇓	*△	σ	⇑⇓	*△	σ		*	
0 to –10°C	⇑	💧		⇑	* 💧		⇑⇓	*△ 💧	σ		*	
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.

TOP, VIL, $REF_{0°C}$, $REF_{-10°C}$, $REF_{-20°C}$

SWIRLS Lightning Alerts for Hong Kong International Airport

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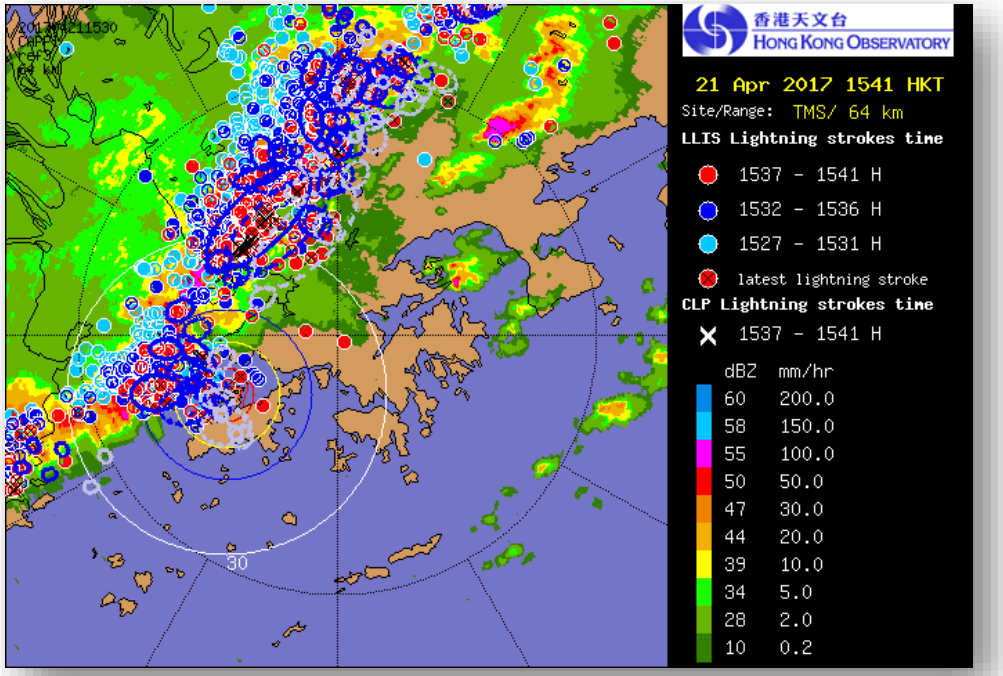
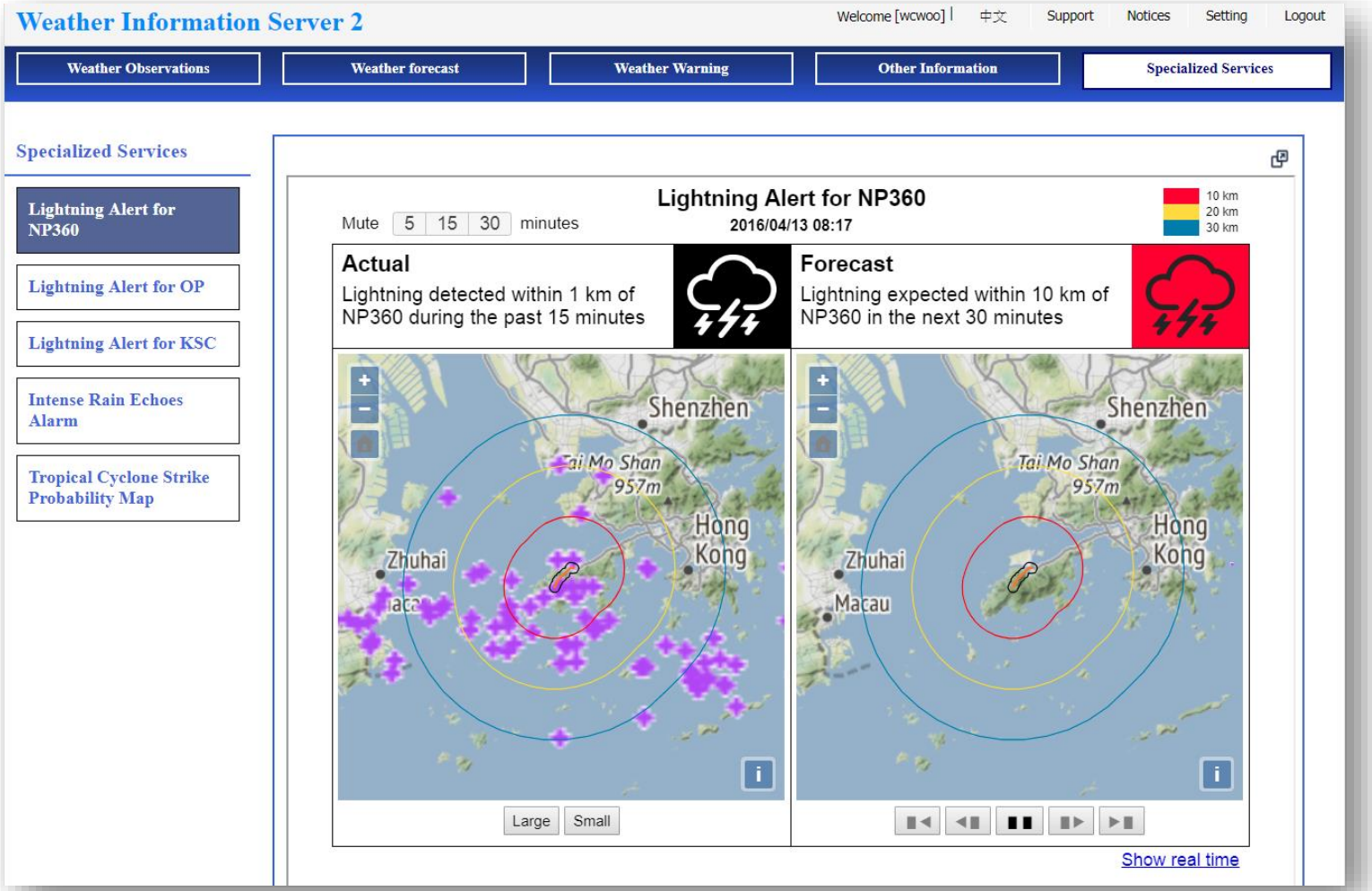
香港機場管理局
AIRPORT AUTHORITY HONG KONG

Minimizes Risk of Lightning Strikes to ground staff in the Airport



Lightning Alert and Nowcasting Services for Public Facilities



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COMMUNITY SWIRLS (COM-SWIRLS)

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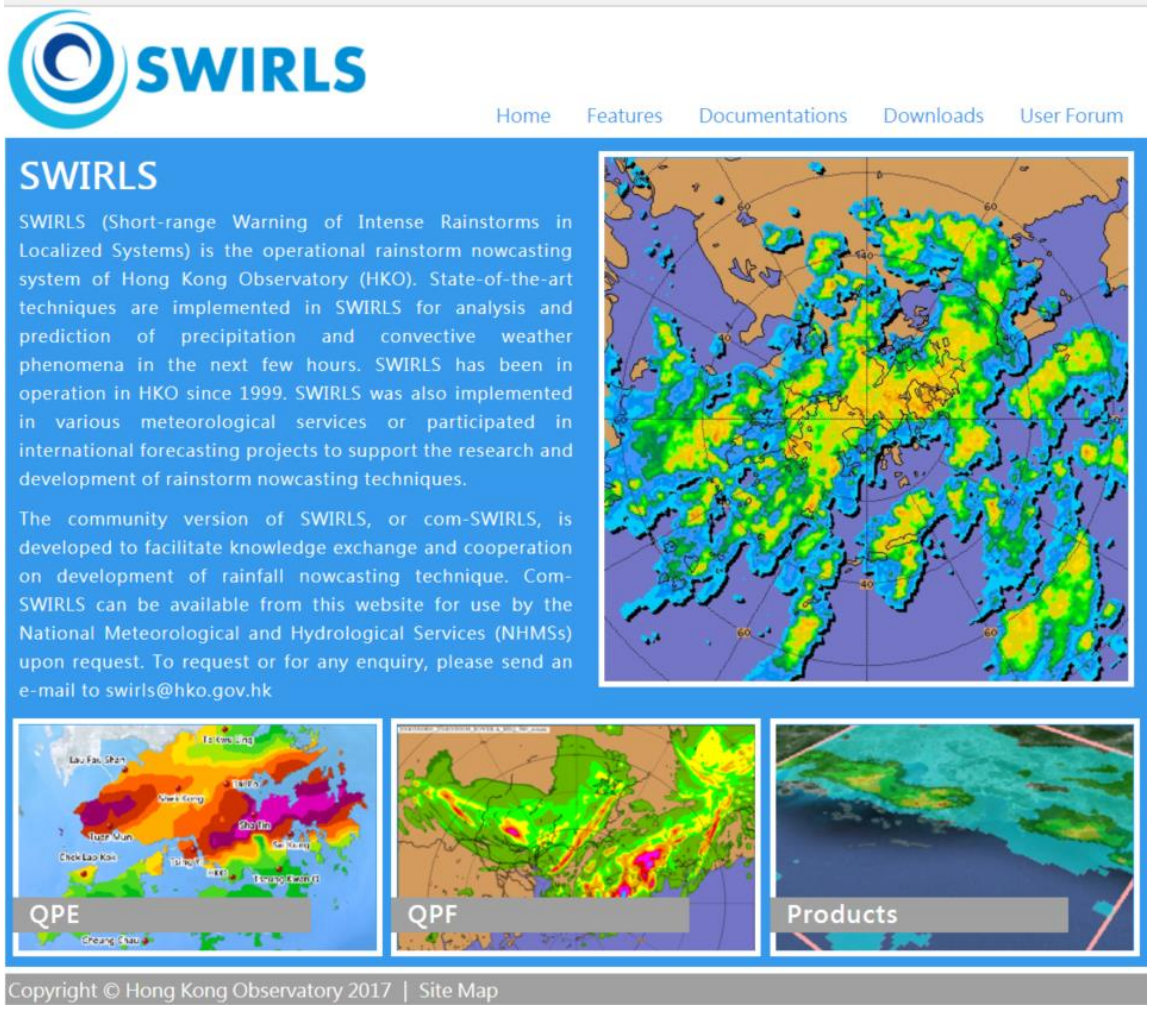
Com-SWIRLS

Website: http://swirls.hko.gov.hk

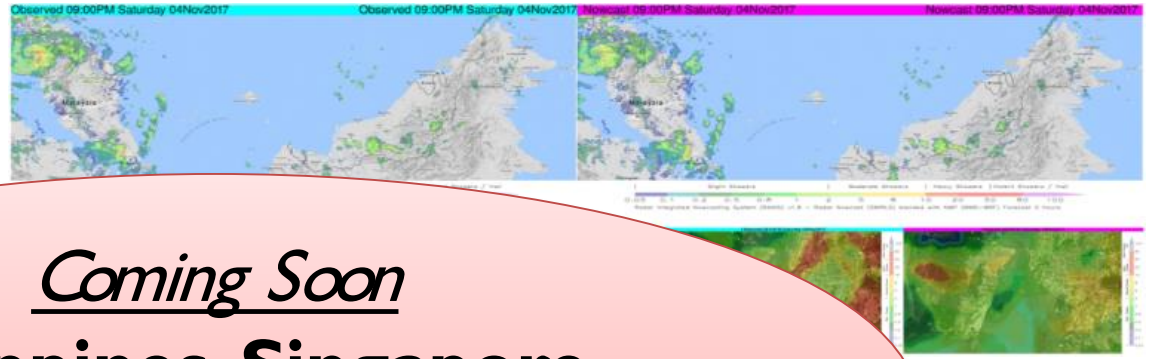
- Capacity building of rainfall nowcasting in NMHSs, promote knowledge exchange and collaboration on research development of rainfall nowcasting techniques

- Com-SWIRLS is developed based on the operational version of SWIRLS, featuring:
  - Quantitative precipitation estimate (QPE), quantitative precipitation forecast (QPF) and graphics utilities to generate rainfall / reflectivity nowcast products
  - Portable code running on common Linux distributions
  - Configurable for implementation in different forecast domains
  - Modular design for easier code changes, and integrate new modules from community users

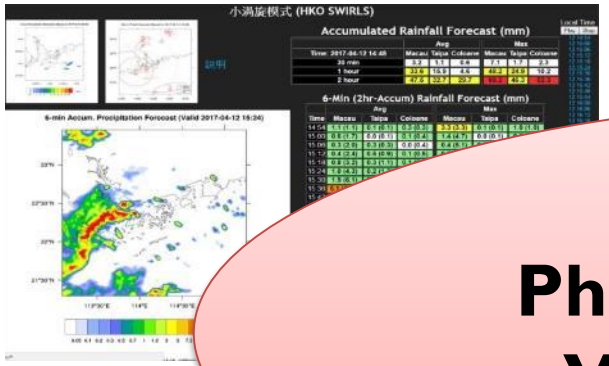


Community SWIRLS Overseas

Malaysia



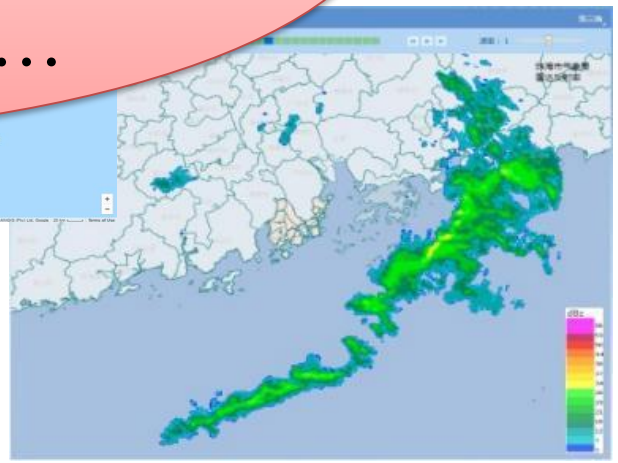
Macao



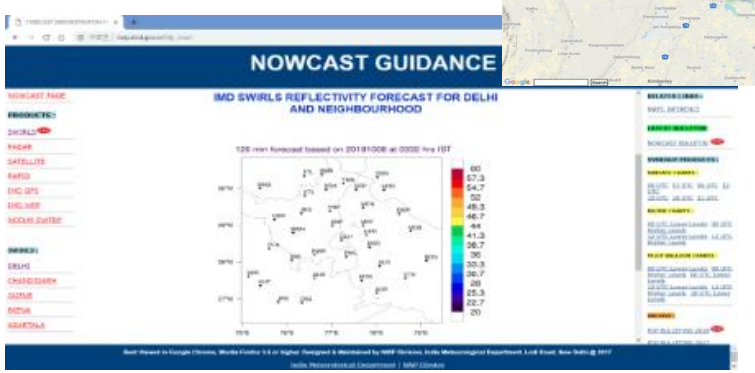
Coming Soon

Philippines, Singapore, Vietnam, Myanmar, Thailand, Indonesia …

South Africa



Zhuhai



India

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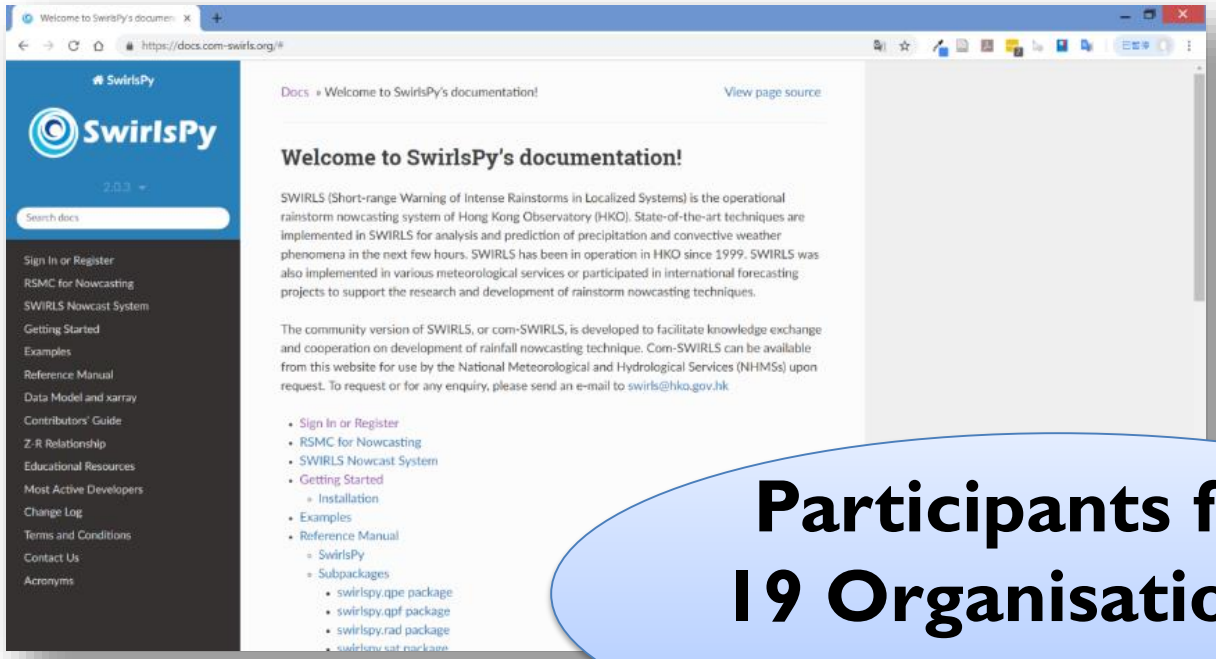
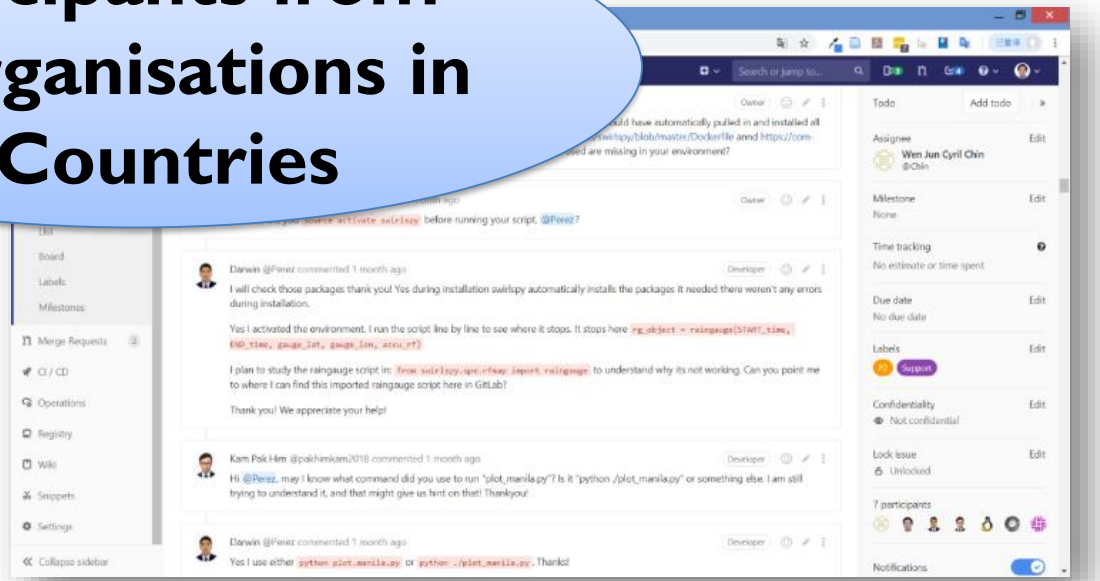
New Com-SWIRLS Collaborative Platform



Participants from
19 Organisations in
9 Countries



Community SWIRLS Nowcast System

Users in Asian countries

Australia
Bangladesh
China
Fiji
India
Indonesia
Japan
Korea
Laos
Macao
Malaysia
Myanmar
Philippines
Singapore
Sri Lanka
Thailand
Vietnam

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Highlights 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

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Com-SWIRLS 1.x vs 2.x

	Com-SWIRLS 1.x	Com-SWIRLS 2.x
Installation	VM	Conda *
Programming Language	Assorted	Primarily Python, plus C++
Graphics 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 Com-SWIRLS/SwirlsPy

User Script

- Developed by the NMHS, assisted by HKO
- Tailored to the specific situation, e.g. warning criteria, database, infrastructure, of that NMHS

```
import os
import numpy as np
import pandas as pd
import xarray as xr
import cartopy.feature as cfeature
import matplotlib.pyplot as plt
from matplotlib.colors import BoundaryNorm, ListedColormap
from pyresample import utils

from swirlspy.rad.uf_ph import read_uf_ph
from swirlspy.qpe.utils import locate_file, timestamps_ending
from swirlspy.qpf import rover
from swirlspy.qpf import sla
from swirlspy.utils import standardize_attr, FrameType
from swirlspy.utils.conversion import to_rainfall_depth, acc_rainfall_depth
from swirlspy.core.resample import grid_resample

plt.switch_backend('agg')

THIS_DIR = os.getcwd()
os.chdir(THIS_DIR)

start_time = pd.Timestamp.now()
```

Import and Call SwirlsPy Modules

Shared Modules (SwirlsPy)

- Developed by HKO Staff and Contributing Developers
- Shared with all NMHSs
- Regularly Updated
- Backward Compatible Whenever Possible

SwirlsPy

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WMO RSMC FOR NOWCASTING

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RSMC for Nowcasting

Opening Ceremony on 2 October 2019 inaugurated by DHKO and Professor Petteri Taalas, Secretary-General of WMO on 2 October 2018

WORLD METEOROLOGICAL ORGANIZATION
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WMO and Hong Kong Observatory strengthen cooperation

Tags: WMO Disaster risk reduction Forecast Tropical cyclones Capacity development

2 **Published** 2 October 2018

Member: Hong Kong, China

WMO has signed an agreement with the Hong Kong Observatory (HKO) to further strengthen meteorological cooperation.

Under a Memorandum of Understanding signed by HKO Director Shun Chi-ming and WMO Secretary-General Petteri Taalas, HKO will support WMO's initiative in establishing the Global Multi-hazard Alert System (GMAS).

In this connection, the HKO has revamped the Severe Weather Information Centre website (SWIC 2.0) and is also

Latest WMO News

— **Three Ways Forward to Improve Regional Information for Extreme Events: An Early Career Perspective**
18 February 2019

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WMO Designated Global Data-processing and Forecasting System Centres

Updated on 24 August 2018

Legend

- World Meteorological Centres* (9)
- Atmospheric Transport Modelling (10)
- 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 (9)
- 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.

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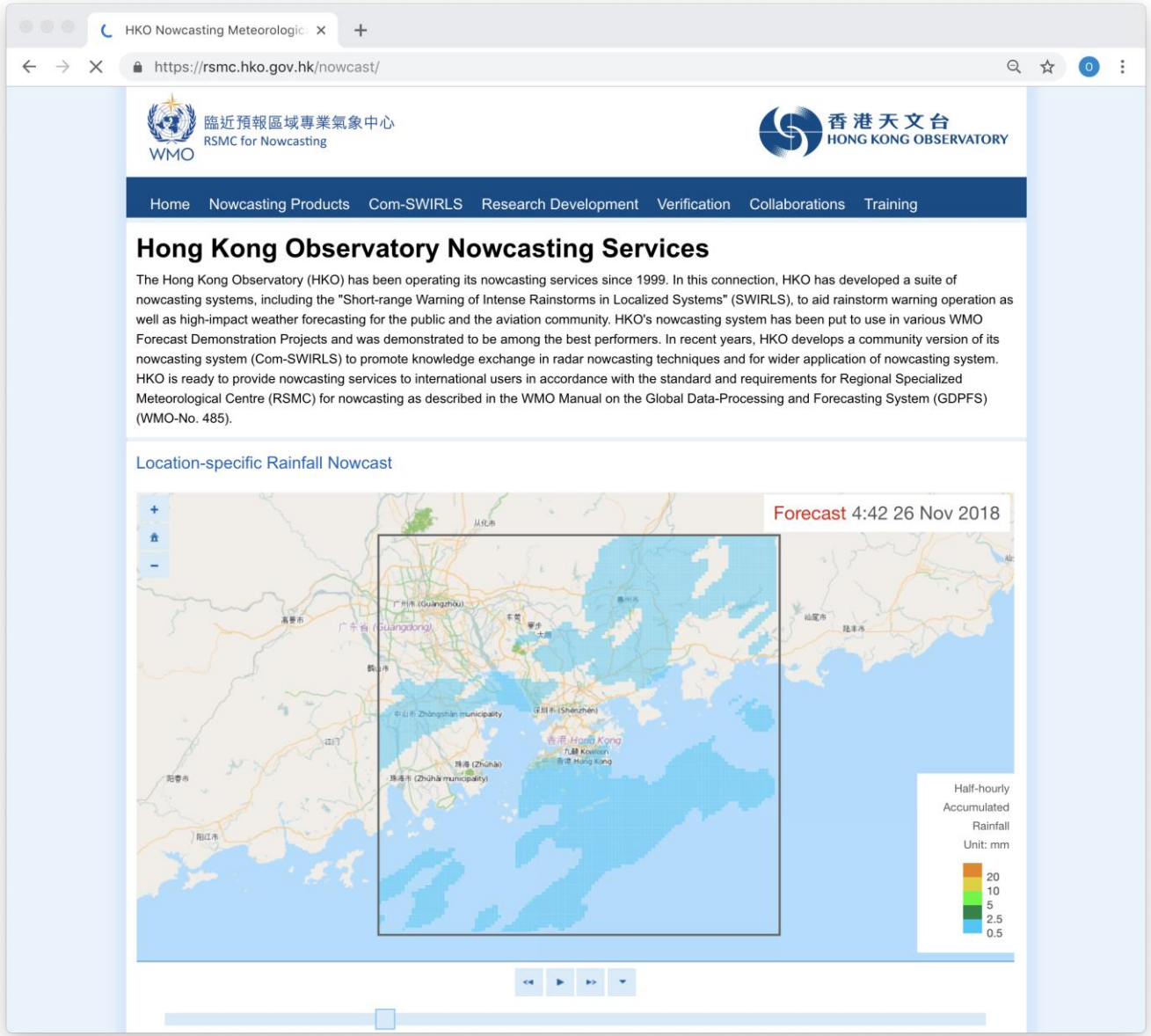
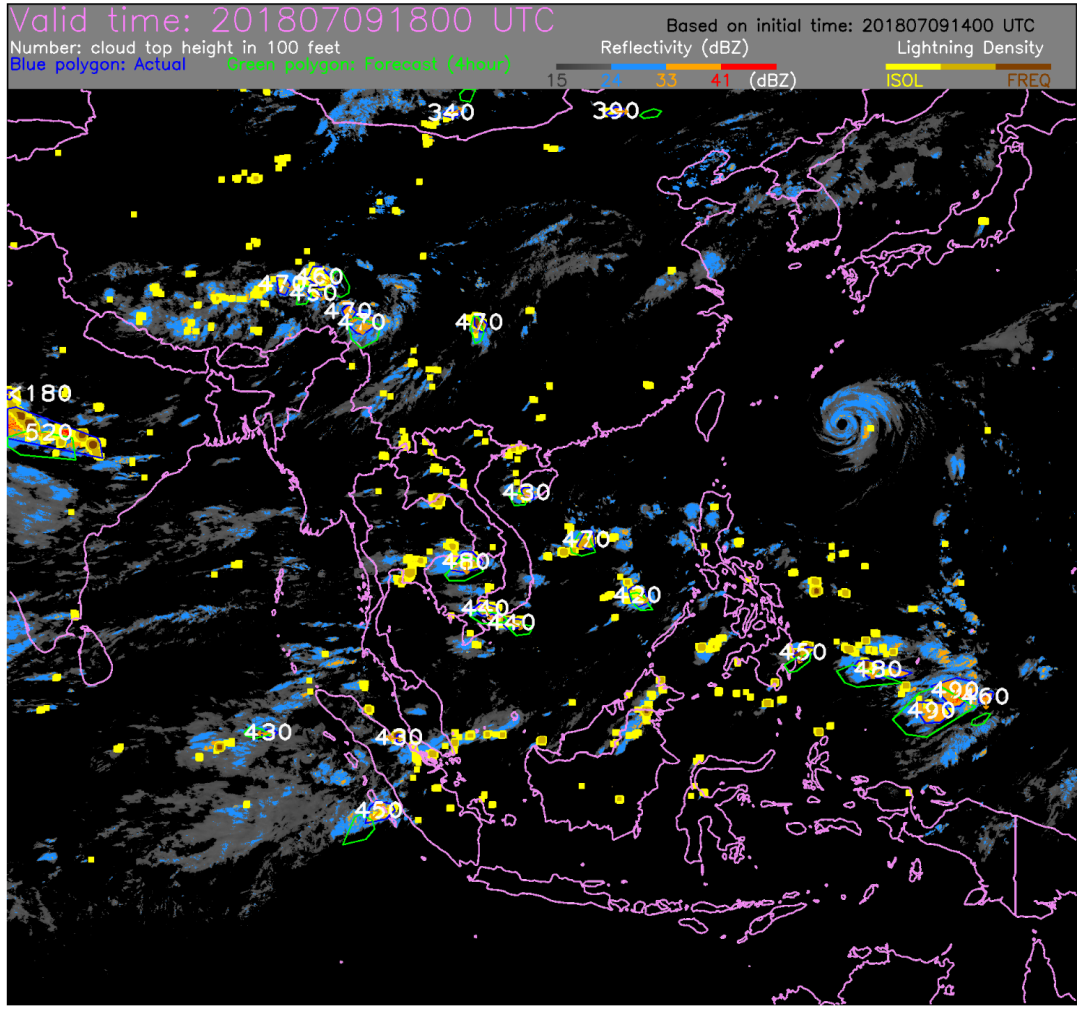
WMO RSMC for Nowcasting

Website: https://rsmc.hko.gov.hk/nowcast/



RSMC Hong Kong (since WMO EC-70 in June 2018)

Significant Convection Nowcast over East Asia



Significant convection nowcast at the fourth hour (in UTC) using retrieved reflectivity (blue ≥24 dBZ, orange ≥33 dBZ and red ≥41 dBZ) from Himawari-8 data and updated every 10 minutes. Lightning counts are marked in yellow (sparse) to brown (dense) with green polygons on areas with high reflectivity or dense lightning.

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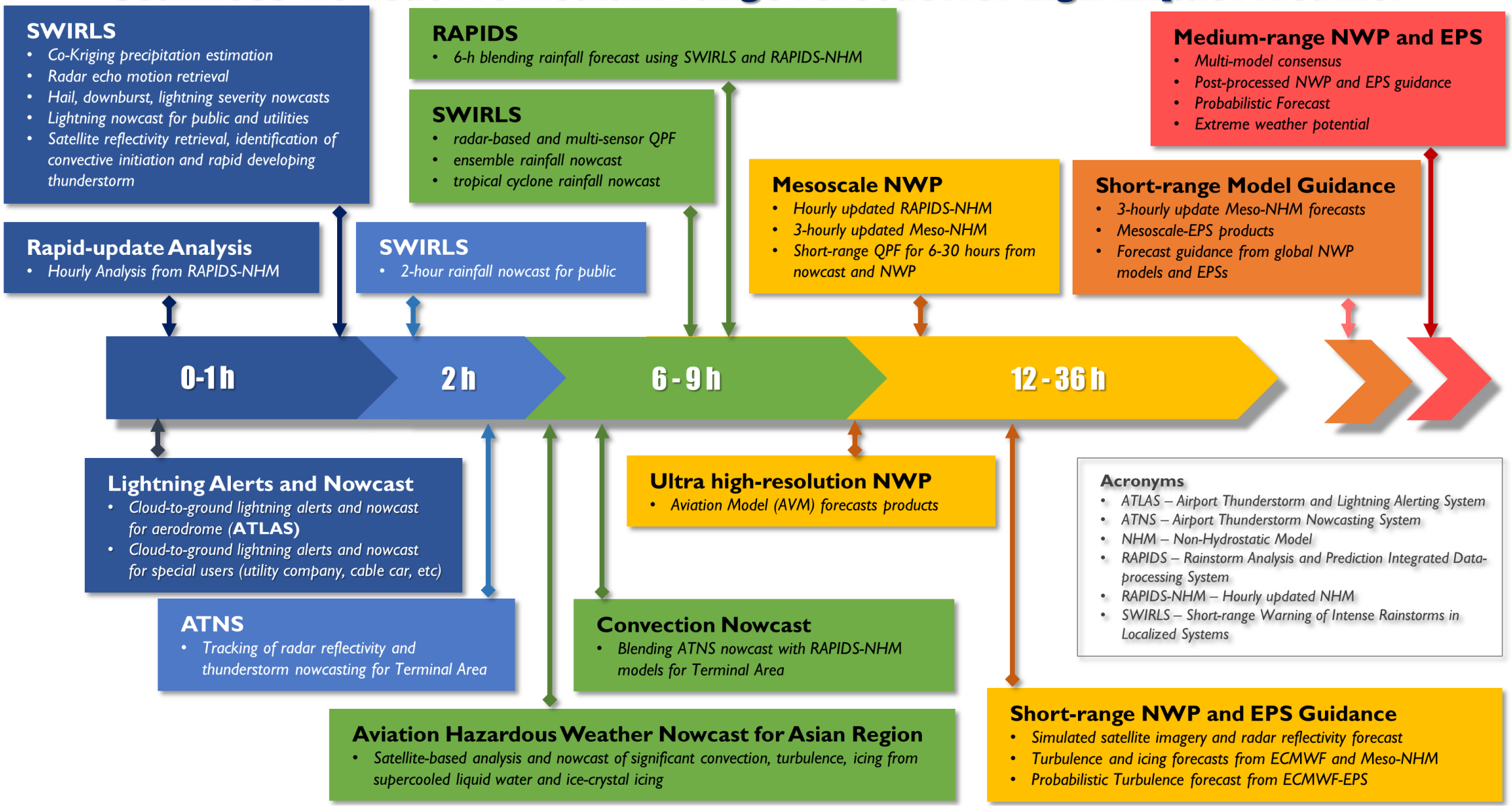
Seamless Nowcast To Medium-range Forecast for High-Impact Weather



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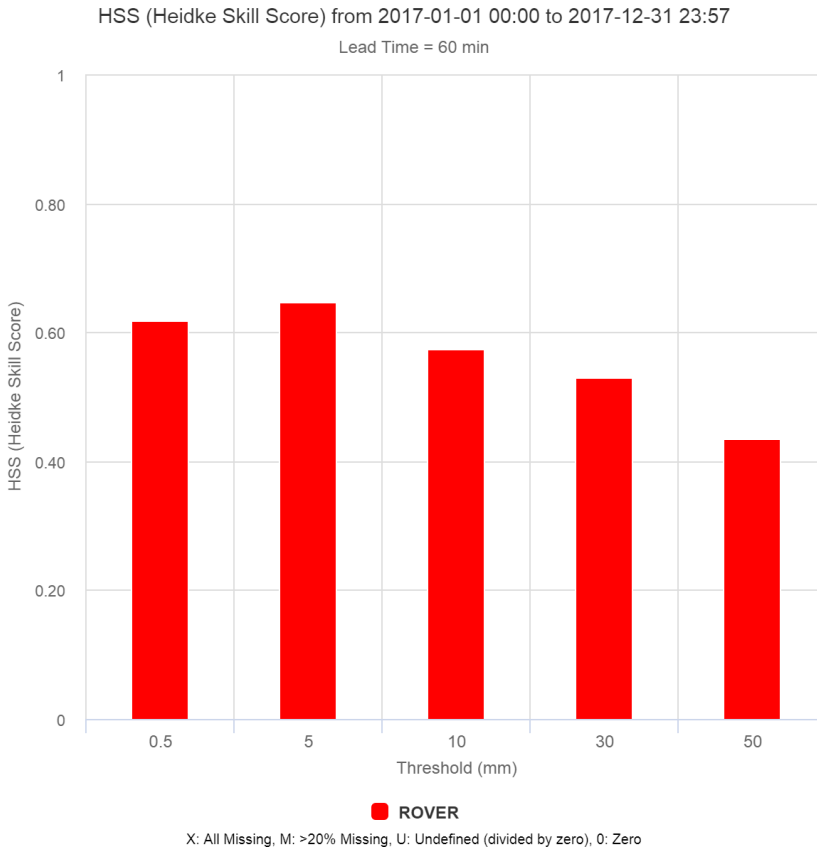
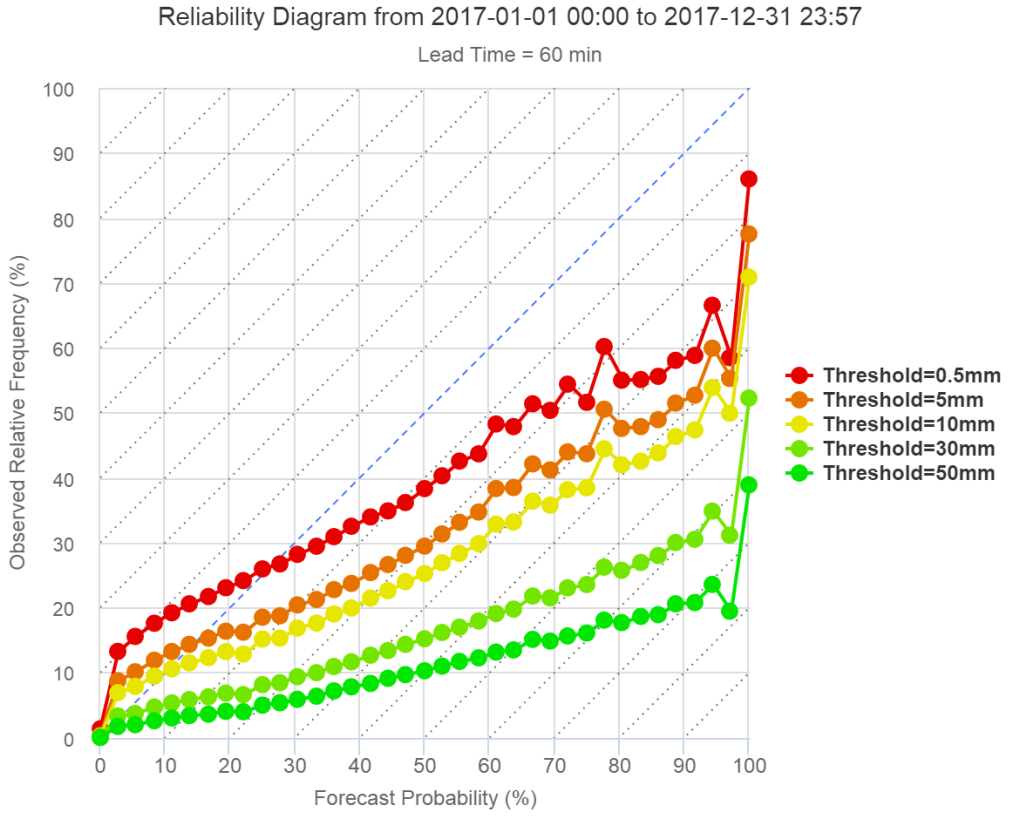
Verifications

https://rsmc.hko.gov.hk/nowcast/verificationBenchmark.html

Heidke Skill Score of 1-h nowcast of different thresholds



Reliability Diagram



Significant Convection Nowcast (2018)

Forecast time	POD	FAR	CSI
0-1st hr	0.945	0.116	0.841
0-2nd hr	0.893	0.114	0.801
0-3rd hr	0.837	0.117	0.754
0-4th hr	0.788	0.120	0.711
0-5th hr	0.747	0.124	0.676
0-6th hr	0.712	0.128	0.645

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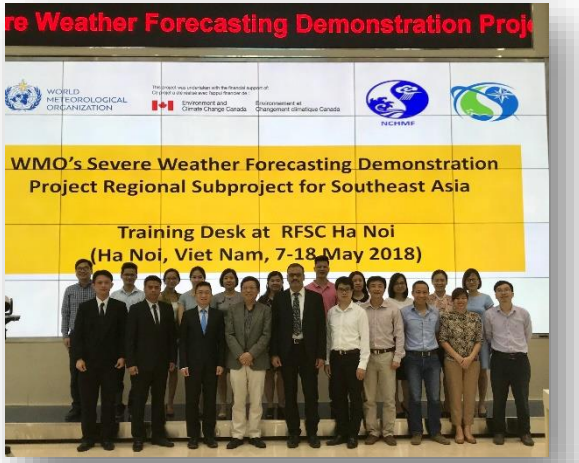
Technology Transfer for Capacity Building on Nowcasting



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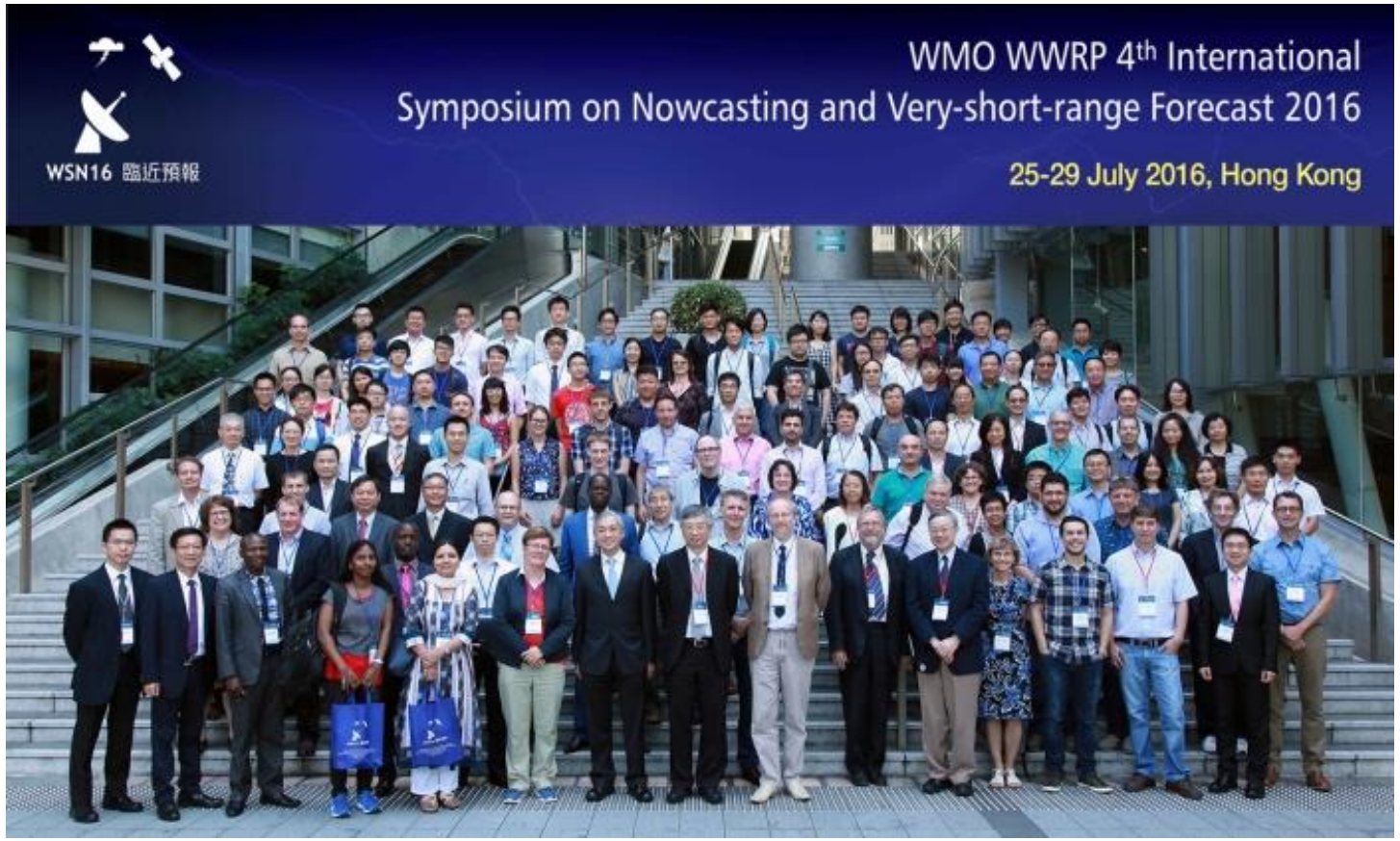
Community Version of SWIRLS (Com-SWIRLS)

Presentation (link) in
WMO Symposium on Nowcasting and Very-short-range Forecast 2016 (WSN16) in Hong Kong



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LATEST DEVELOPMENTS

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Deep Learning Nowcast

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Deep Learning Nowcast in SWIRLS

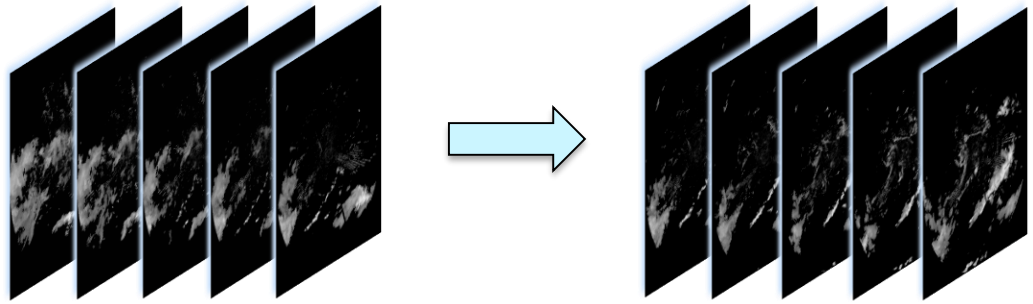
- A Brief History

Year	Event
2014	Initiated collaboration with HKUST
2015	ConvLSTM developed, outperforming ROVER for rain/no-rain (0.5 mm/h), resolution limited to 100x100 only
2016	Model enhancement and adaptation
2017	TrajGRU developed and benchmarked, outperforming ROVER for 30mm/h support arbitrary resolution
2018	Commence operational trial of TrajGRU

- Predicting evolution of weather radar imagery

Input sequence:
observed radar maps up to current time step

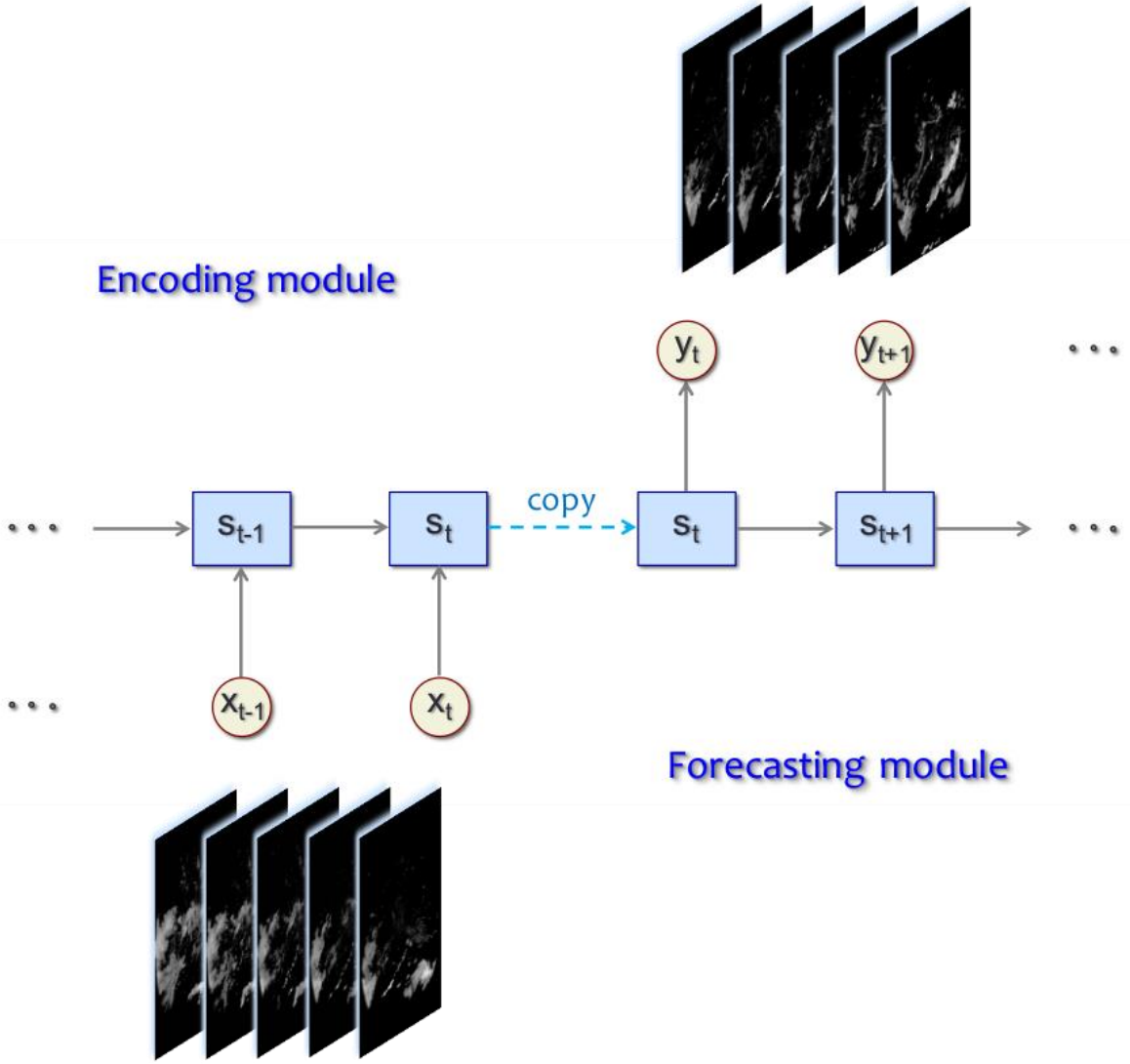
Output sequence:
predicted radar maps for future time steps



Mathematically to maximize posterior pdf of echo sequence across K time levels based on previous J time levels of observations

$$\tilde{\mathcal{X}}_{t+1}, \ldots, \tilde{\mathcal{X}}_{t+K} = \underset{\mathcal{X}_{t+1}, \ldots, \mathcal{X}_{t+K}}{\arg\max} \; p(\mathcal{X}_{t+1}, \ldots, \mathcal{X}_{t+K} \mid \hat{\mathcal{X}}_{t-J+1}, \hat{\mathcal{X}}_{t-J+2}, \ldots, \hat{\mathcal{X}}_{t})$$

Spatiotemporal encoding-forecasting model

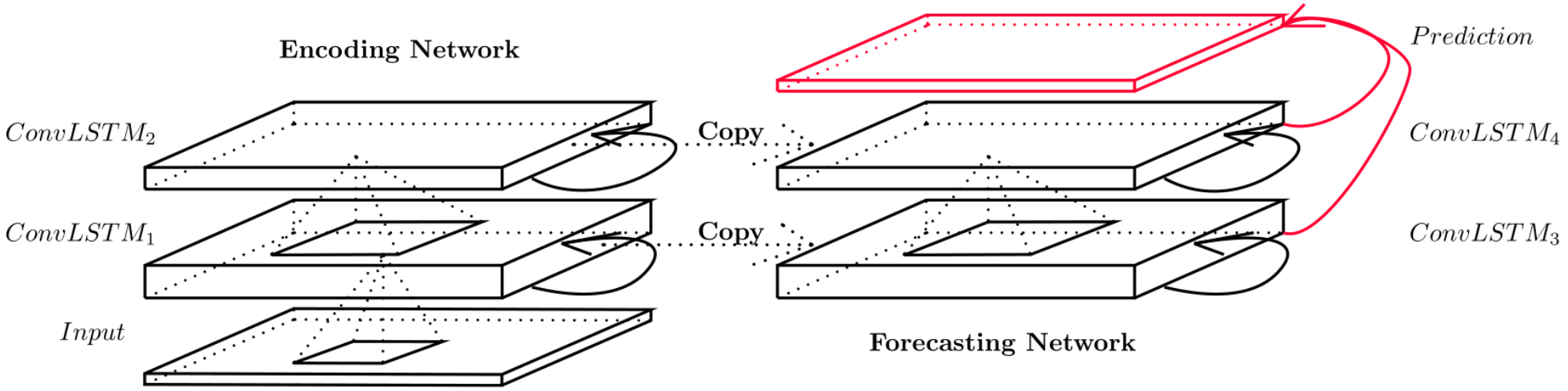


- Convolutional Long Short Term Memory (ConvLSTM) model
  - X. Shi, Z. Chen, H. Wang, D. Y. Yeung, W. K. Wong, and W. C. Woo, 2015: Convolutional LSTM network: A machine learning approach for precipitation nowcasting. NIPS 2015.

    Link: https://arxiv.org/abs/1506.04214
- Two key components:
  - Convolutional layers
  - Long short-term memory (LSTM) cells in recurrent neural network (RNN) model

Encoding and Forecasting Networks in ConvLSTM

- Last states and cell outputs of encoding network become initial states and cell outputs of forecasting network
- **Encoding network** compresses the input sequence into a hidden state tensor
- **Forecasting network** unfolds the hidden state tensor to make prediction



Governing Equations in ConvLSTM

Inputs

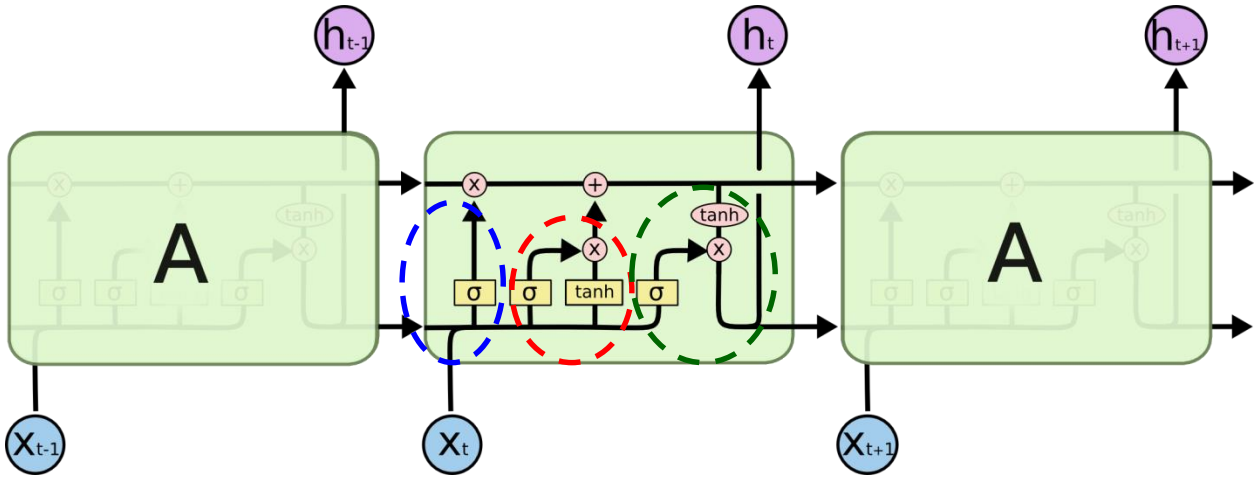
input gate $i_t = \sigma(W_{xi} * \mathcal{X}_t + W_{hi} * \mathcal{H}_{t-1} + W_{ci} \circ \mathcal{C}_{t-1} + b_i)$

forget gate $f_t = \sigma(W_{xf} * \mathcal{X}_t + W_{hf} * \mathcal{H}_{t-1} + W_{cf} \circ \mathcal{C}_{t-1} + b_f)$

Cell outputs $\mathcal{C}_t = f_t \circ \mathcal{C}_{t-1} + i_t \circ \tanh(W_{xc} * \mathcal{X}_t + W_{hc} * \mathcal{H}_{t-1} + b_c)$

output gate $o_t = \sigma(W_{xo} * \mathcal{X}_t + W_{ho} * \mathcal{H}_{t-1} + W_{co} \circ \mathcal{C}_t + b_o)$

Hidden states $\mathcal{H}_t = o_t \circ \tanh(\mathcal{C}_t)$



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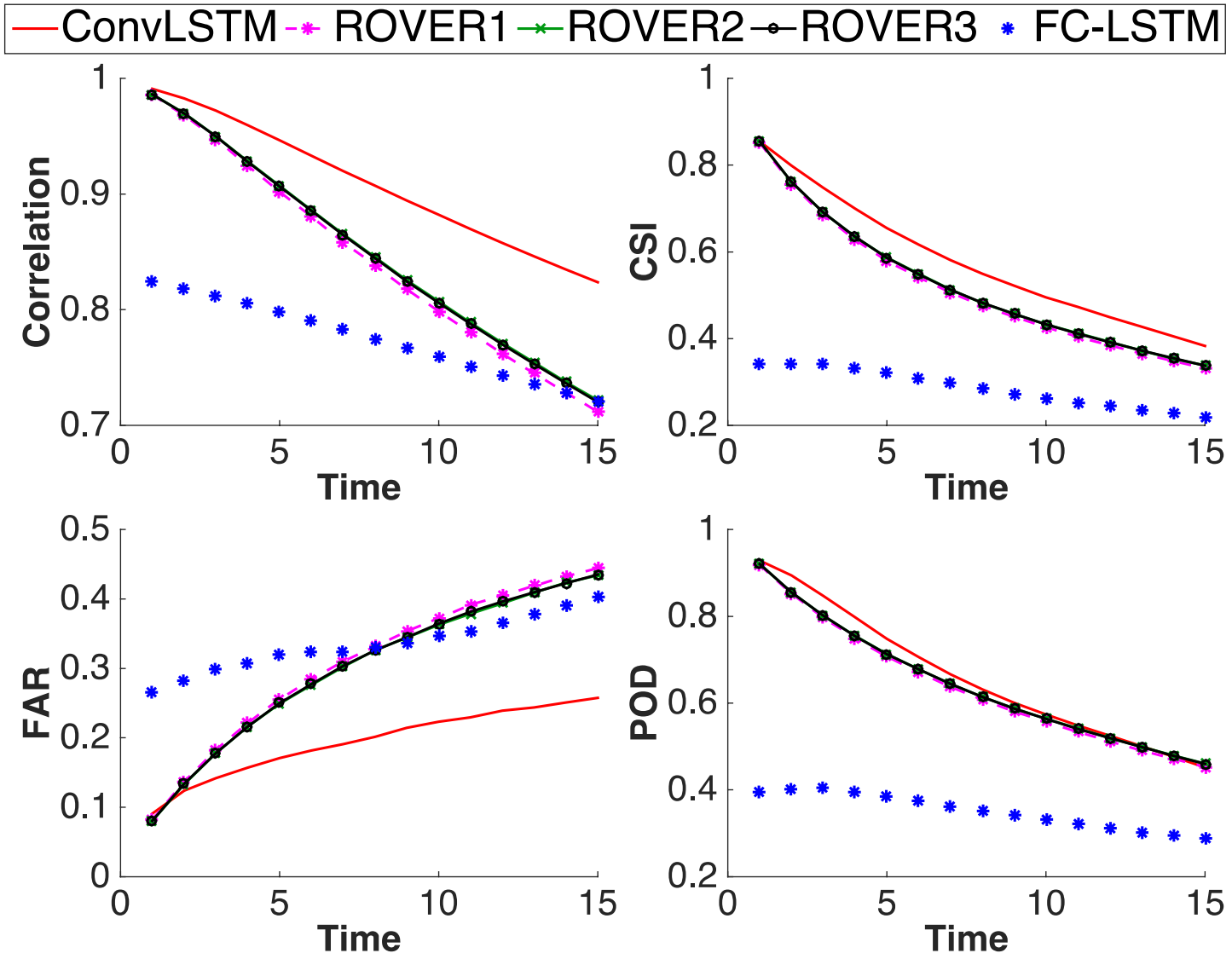
Forecast performance vs. lead time



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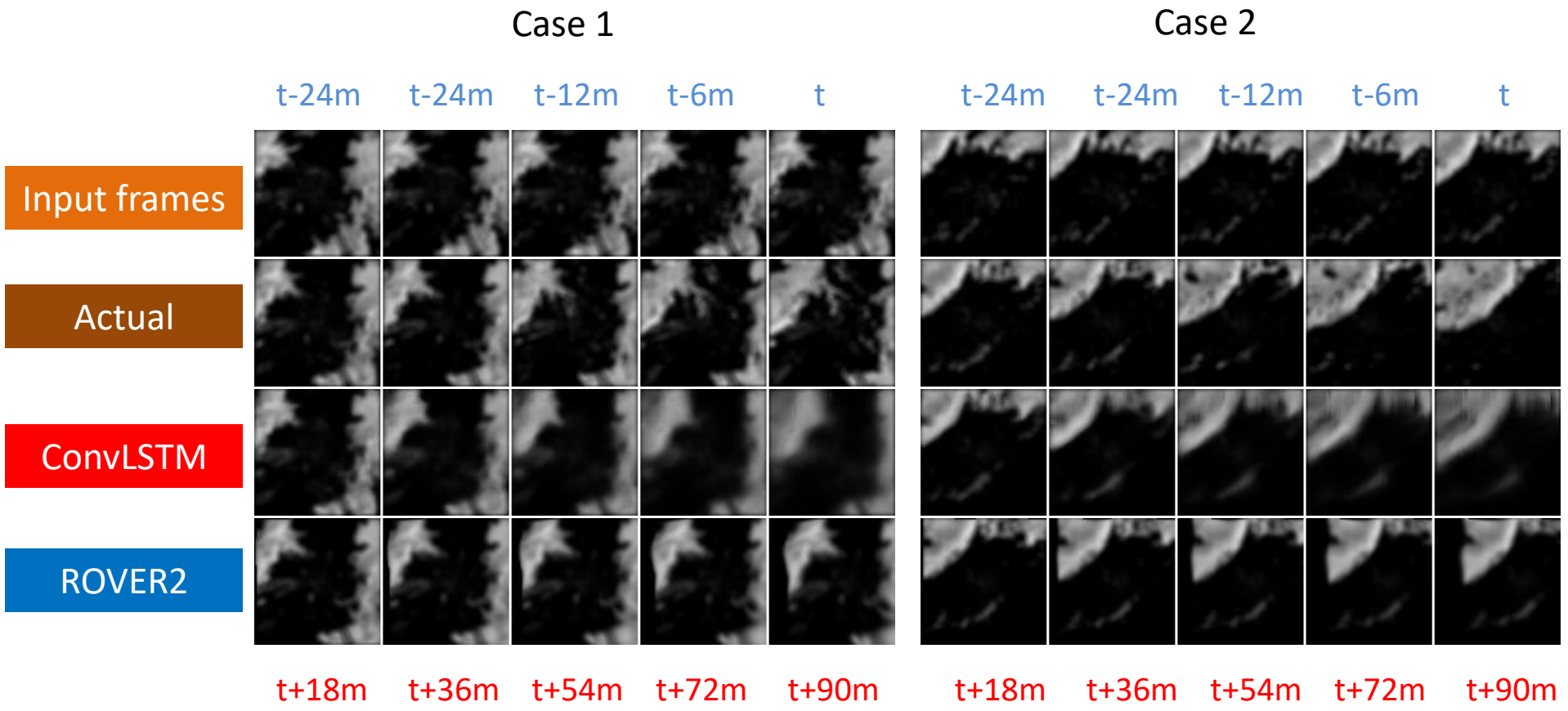
Two squall line cases

- Radar located at center
- 5 input frames are used and a total of 15 frames (i.e. T+90 min) in forecasts



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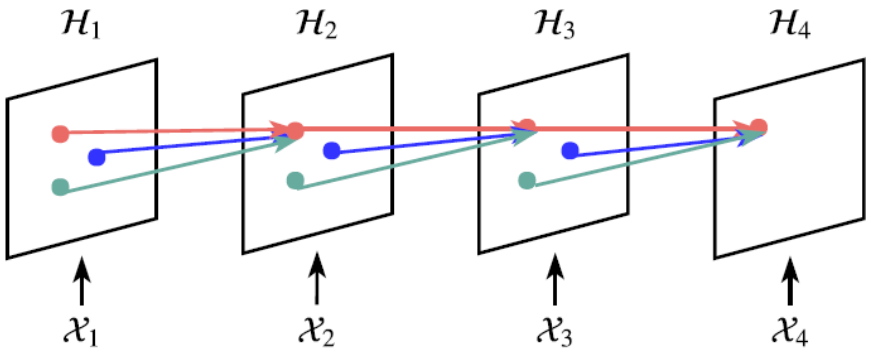
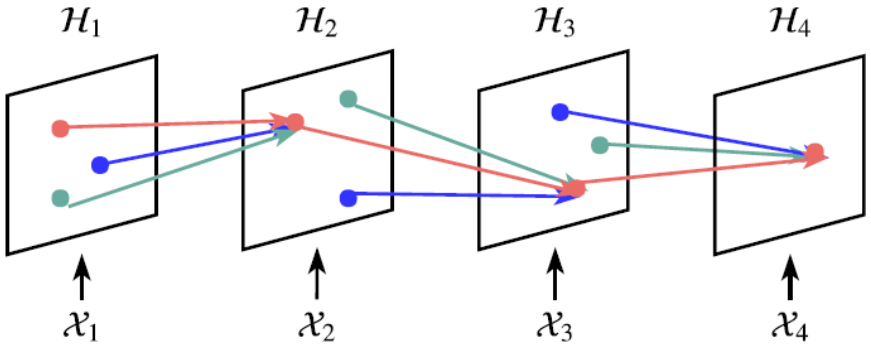
A New Model for Deep Learning in Nowcast

Trajectory Gated Recurrent Unit (TrajGRU)



(a) ConvRNN: Links are fixed over time/location.



(b) TrajRNN: Links are dynamically determined.

https://arxiv.org/pdf/1706.03458.pdf

Deep Learning for Precipitation Nowcasting: A Benchmark and A New Model

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Abstract

With the goal of making high-resolution forecasts of regional rainfall, precipitation nowcasting has become an important and fundamental technology underlying various public services ranging from rainstorm warnings to flight safety. Recently, the *Convolutional LSTM* (ConvLSTM) model has been shown to outperform traditional optical flow based methods for precipitation nowcasting, suggesting that deep learning models have a huge potential for solving the problem. However, the convolutional recurrence structure in ConvLSTM-based models is *location-invariant* while natural motion and transformation (e.g., rotation) are *location-variant* in general. Furthermore, since deep-learning-based precipitation nowcasting is a newly emerging area, clear evaluation protocols have not yet been established. To address these problems, we propose both a new model and a benchmark for precipitation nowcasting. Specifically, we go beyond ConvLSTM and propose the *Trajectory GRU* (TrajGRU) model that can actively learn the *location-variant* structure for recurrent connections. Besides, we provide a benchmark that includes a real-world large-scale dataset from the Hong Kong Observatory, a new training loss, and a comprehensive evaluation protocol to facilitate future research and gauge the state of the art.

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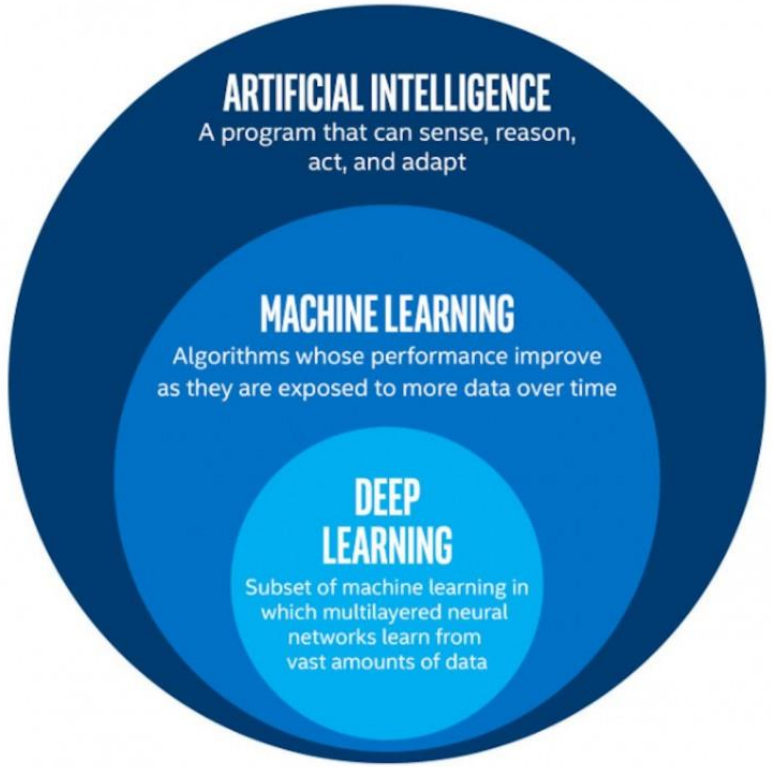
Performance

TrajGRU outperformed operational method and other deep-learning techniques, **in particular for heavy rain r>=30 mm in 1 h**, based on 7-years of radar data

Algorithms	HSS ↑ $r \geq 0.5$	$r \geq 2$	$r \geq 5$	$r \geq 10$	$r \geq 30$	B-MSE ↓	B-MAE ↓
Offline Setting							
Last Frame	0.5207	0.4531	0.3582	0.2512	0.1193	15274	28042
ROVER + Linear	0.6038	0.5473	0.4516	0.3301	0.1762	11651	23437
ROVER + Non-linear	0.5896	0.5436	0.4590	0.3318	0.1576	10945	22857
2D CNN	0.6366	0.5809	0.4851	0.3690	0.1885	7332	18091
3D CNN	0.6334	0.5825	0.4862	0.3734	0.2034	7202	17593
ConvGRU-nobal	0.6756	0.6094	0.4981	0.3286	0.1160	9087	19642
ConvGRU	0.6701	0.6104	0.5163	0.4159	0.2893	5951	15000
TrajGRU	**0.6731**	**0.6126**	**0.5192**	**0.4207**	**0.2996**	**5816**	**14675**
Online Setting							
2D CNN	0.6365	0.5756	0.4790	0.3744	0.2162	6654	17071
3D CNN	0.6355	0.5736	0.4766	0.3733	0.2220	6690	16903
ConvGRU	0.6712	0.6105	0.5183	0.4226	0.2981	5724	14772
TrajGRU	**0.6760**	**0.6164**	**0.5253**	**0.4308**	**0.3111**	**5589**	**14465**



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TrajGRU and HKO-7 Benchmark Dataset

- TrajGRU available to public on GitHub:
  - https://github.com/sxjscience/HKO-7

- The 7-years of HKO radar image archive as benchmark for development of deep learning in nowcasting and other weather application from the above Github repository
  - Available to researchers and weather services subject to agreement to the undertaking

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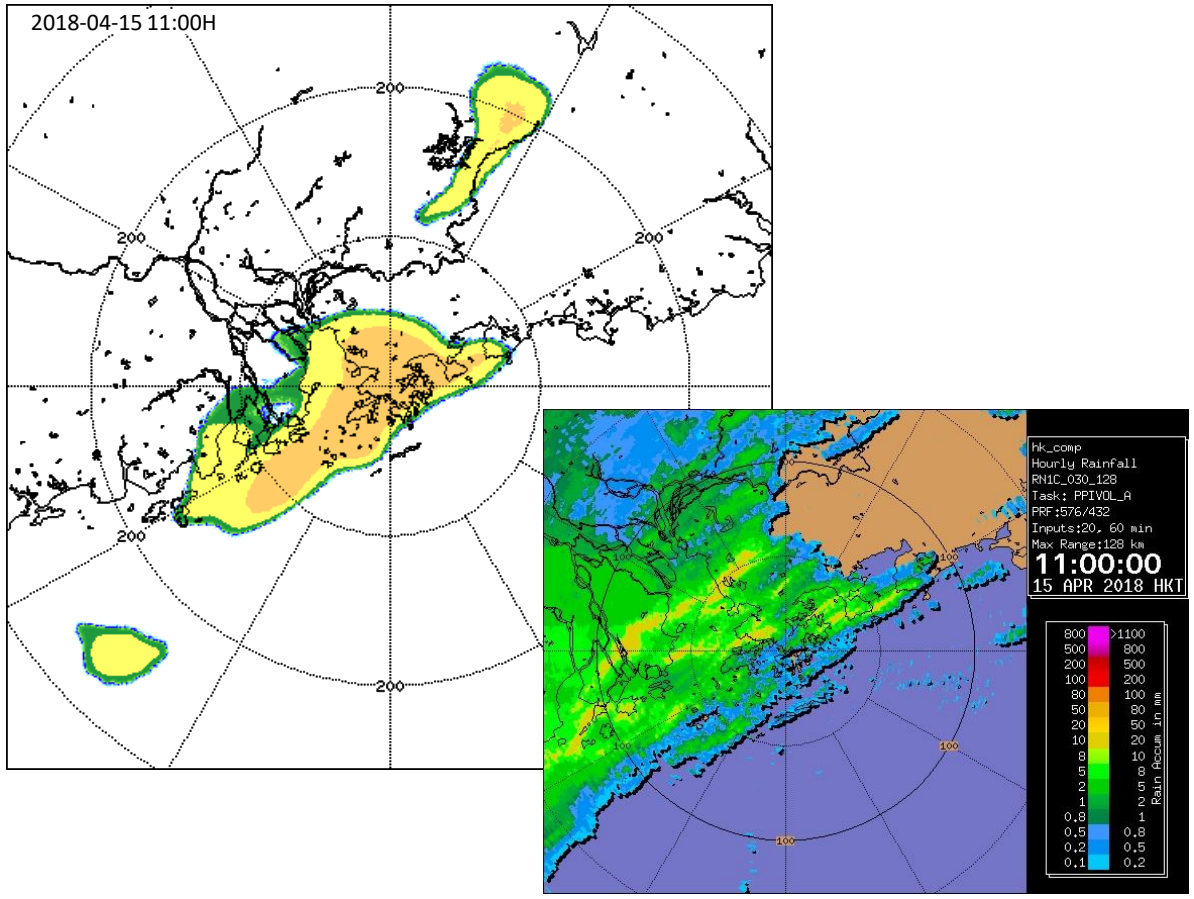
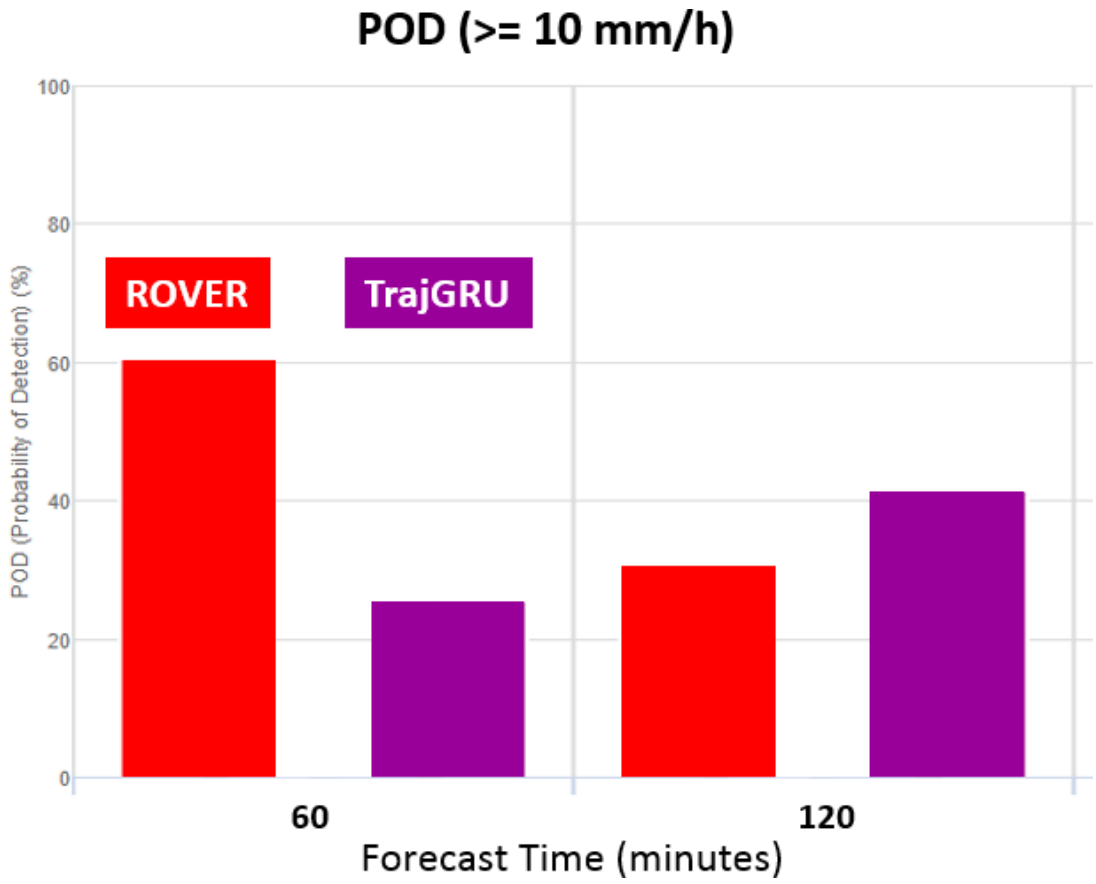
TrajGRU in real-time trial

T+60 min TrajGRU Nowcast



Verification Period: May – Sept 2018



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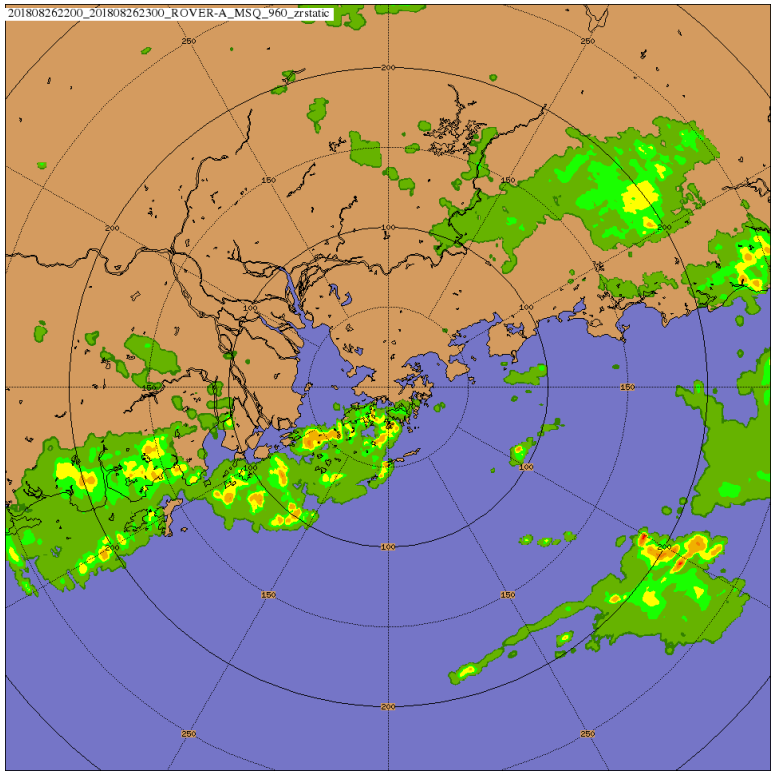
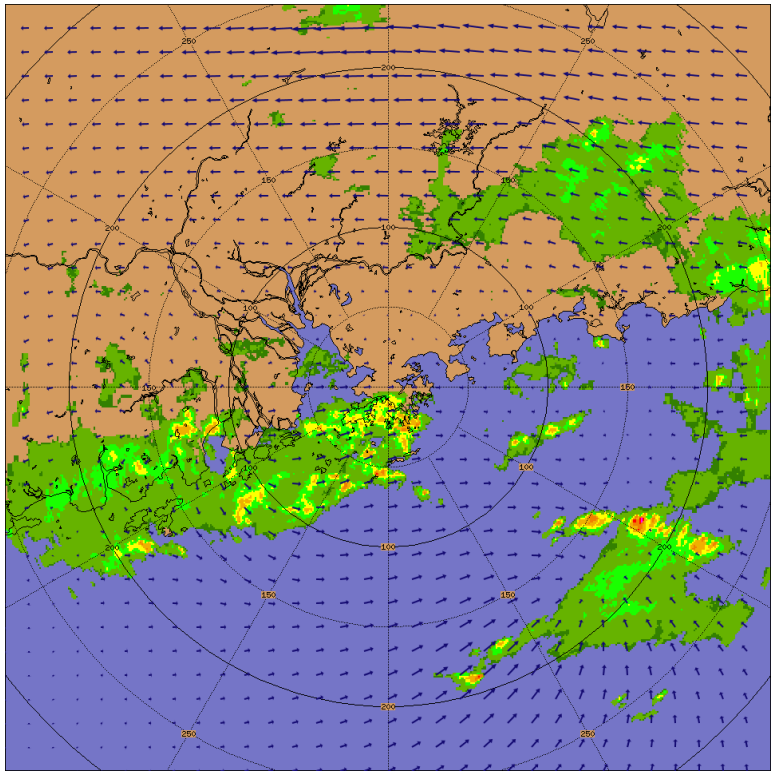
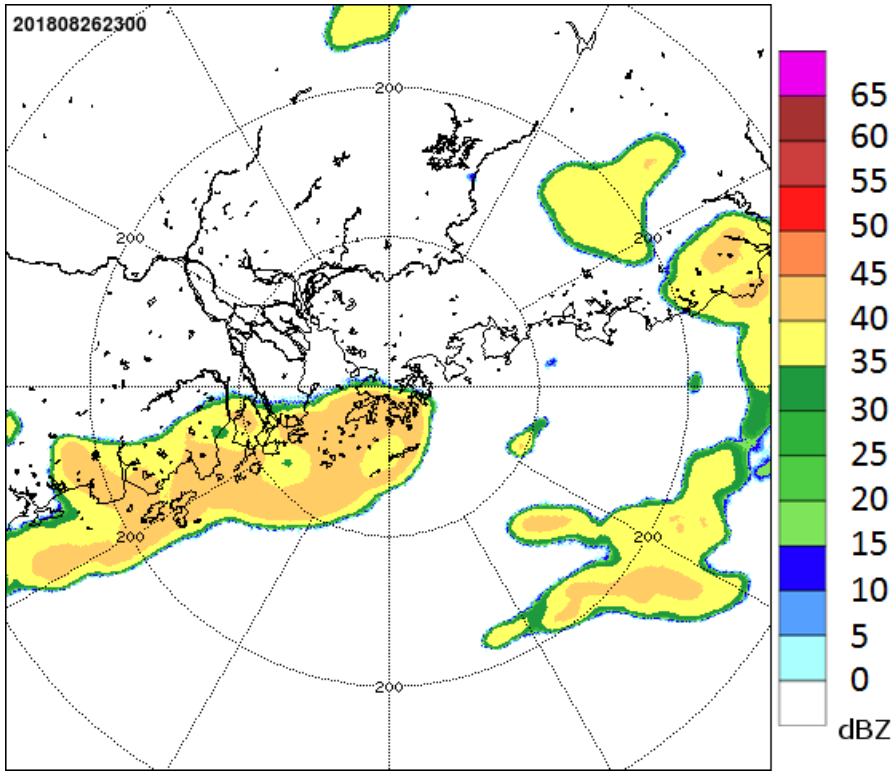
60-min Forecast Reflectivity
Based at 2018/08/26 23:00H

23:05







Optical Flow (ROVER)

Actual

Deep Learn (TrajGRU)

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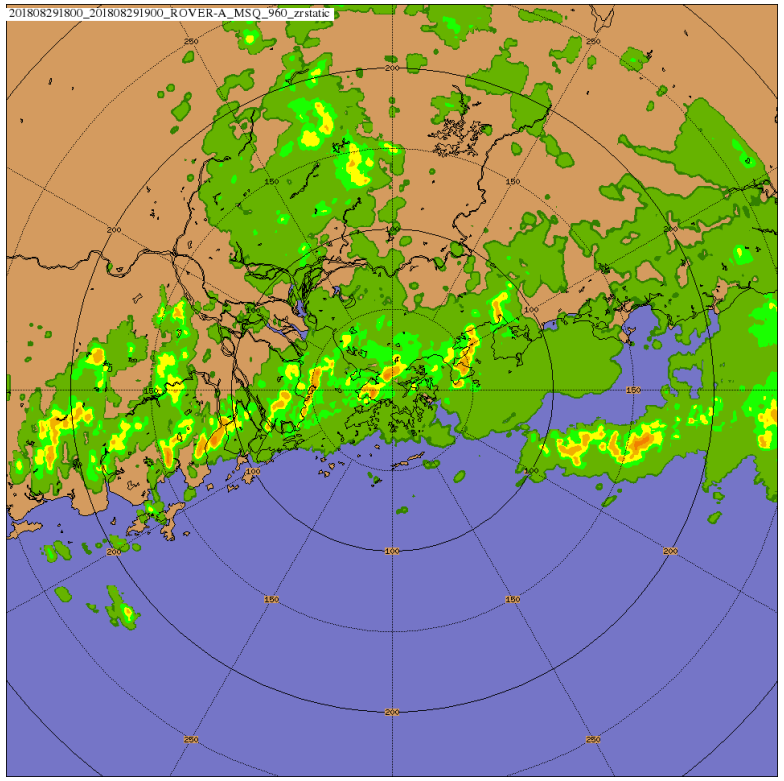
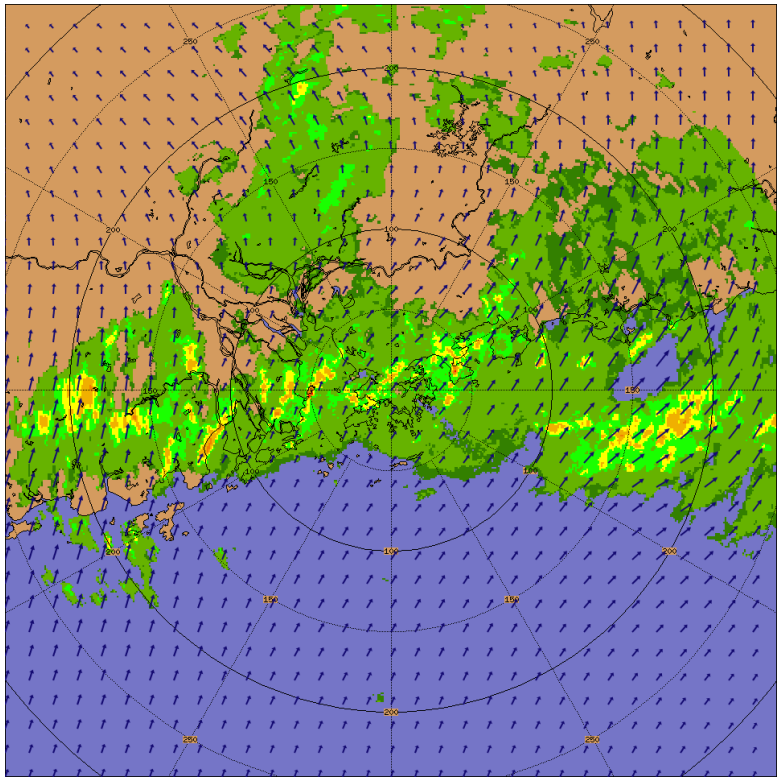
60-min Forecast Reflectivity
Based at 2018/08/29 18:00

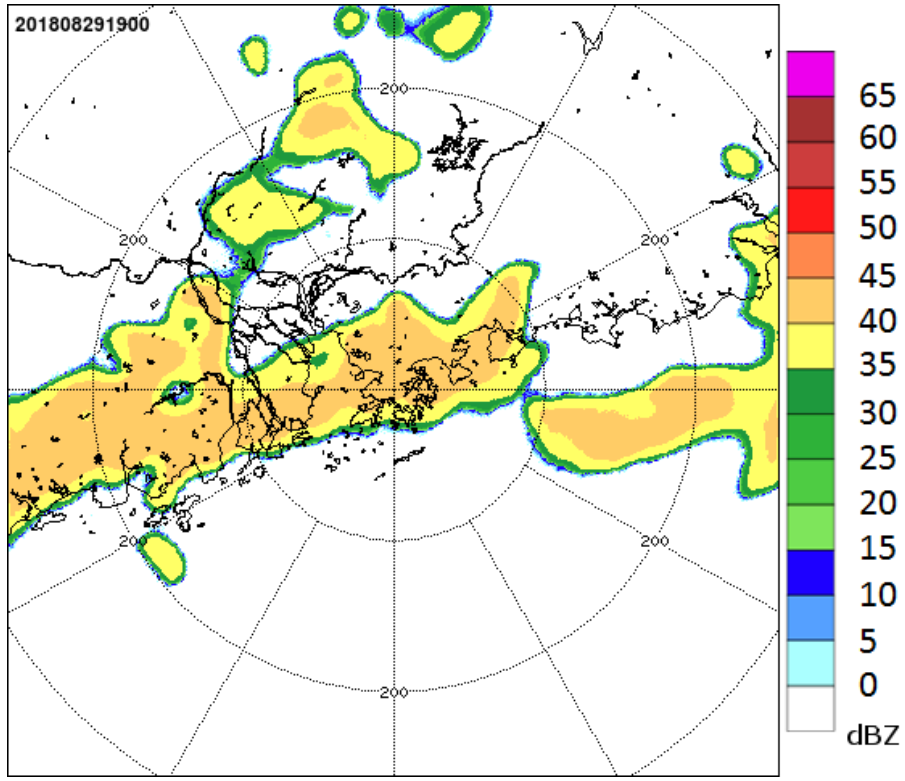
Red 紅 18:40



Optical Flow (ROVER)



Actual



Deep Learn (TrajGRU)

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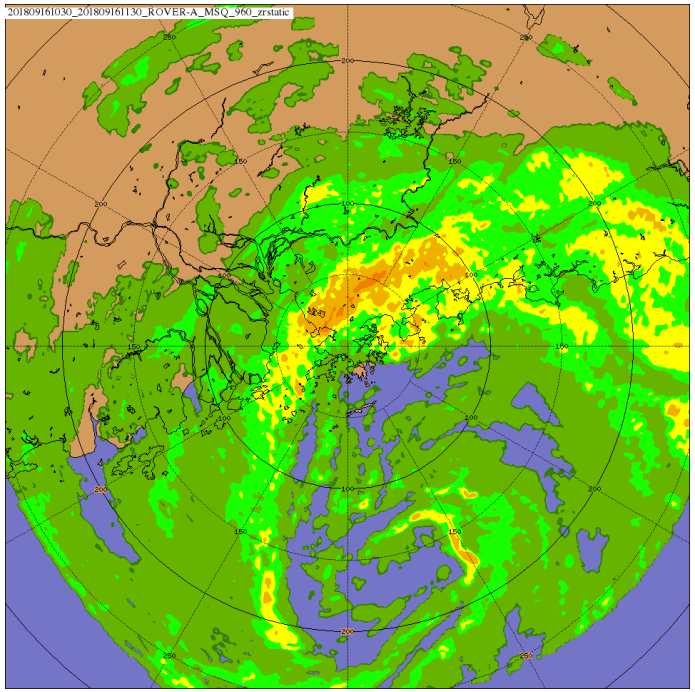
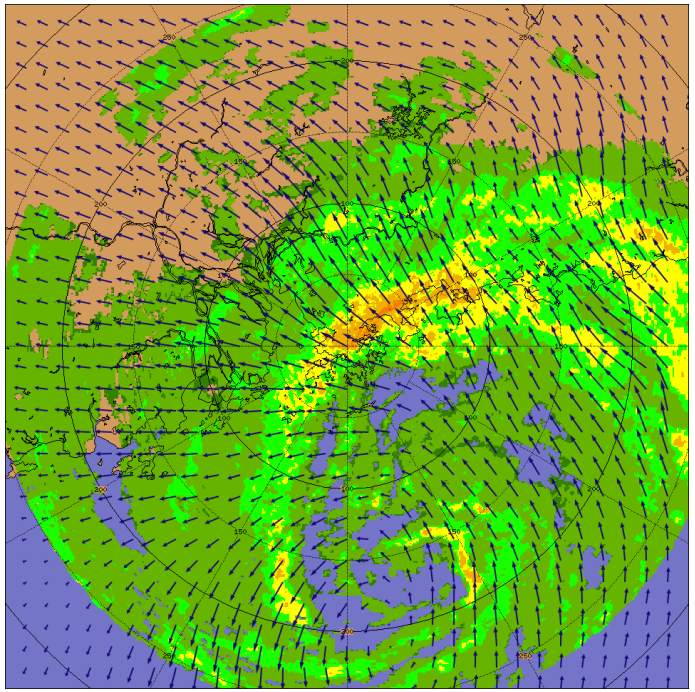
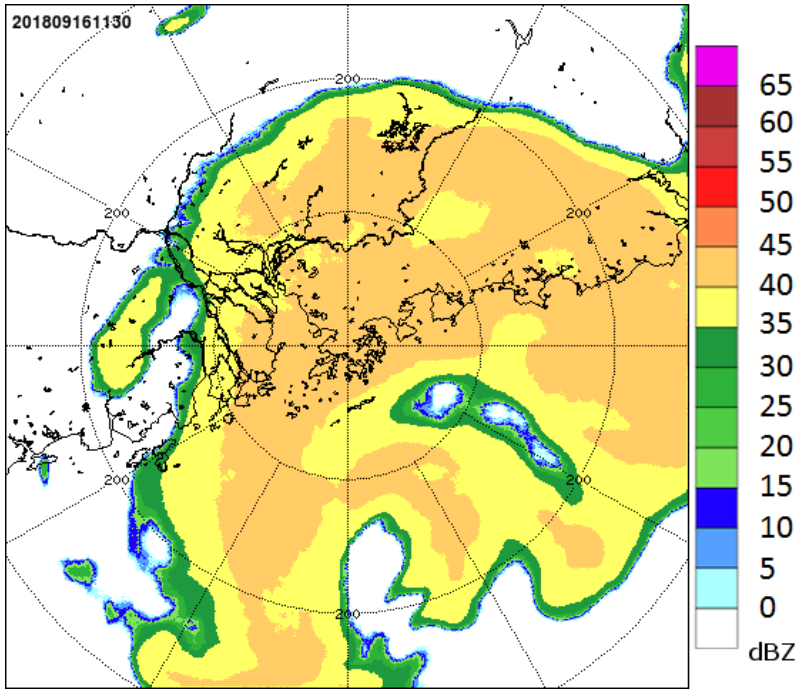
60-min Forecast Reflectivity
Based at 2018/09/16 10:30

Amber 黃 09:10







Optical Flow (ROVER)

Actual

Deep Learn (TrajGRU)

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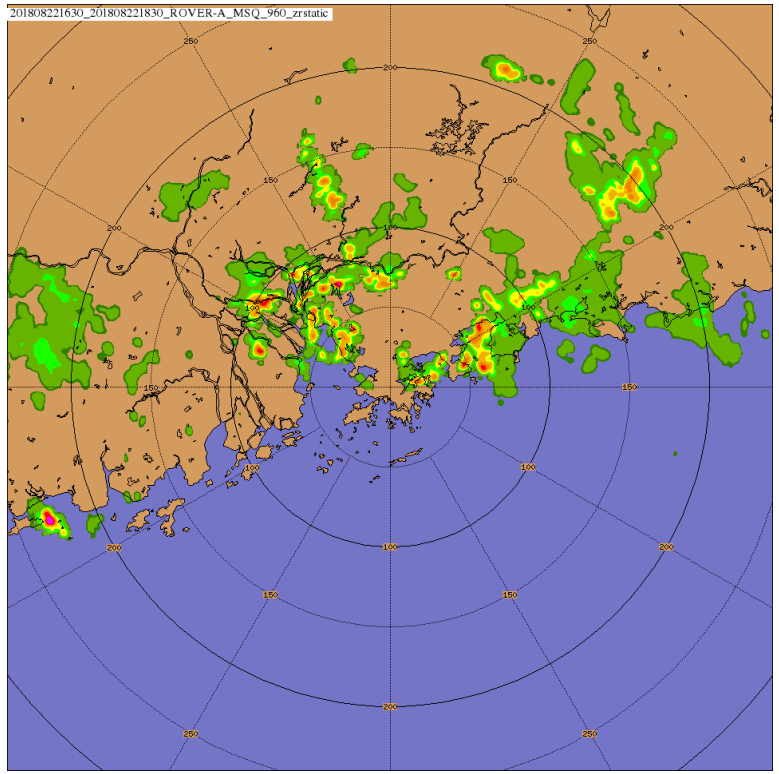
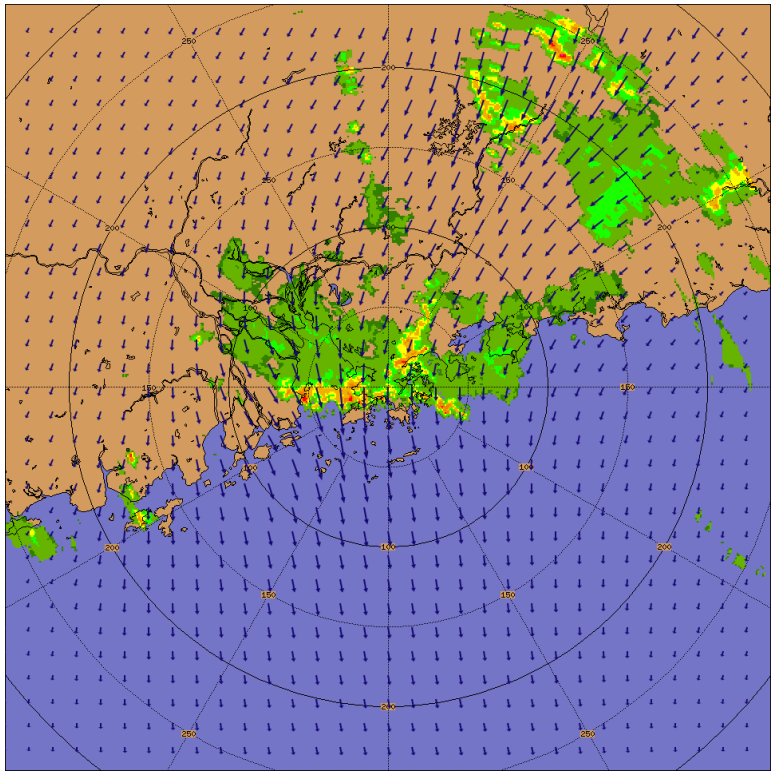
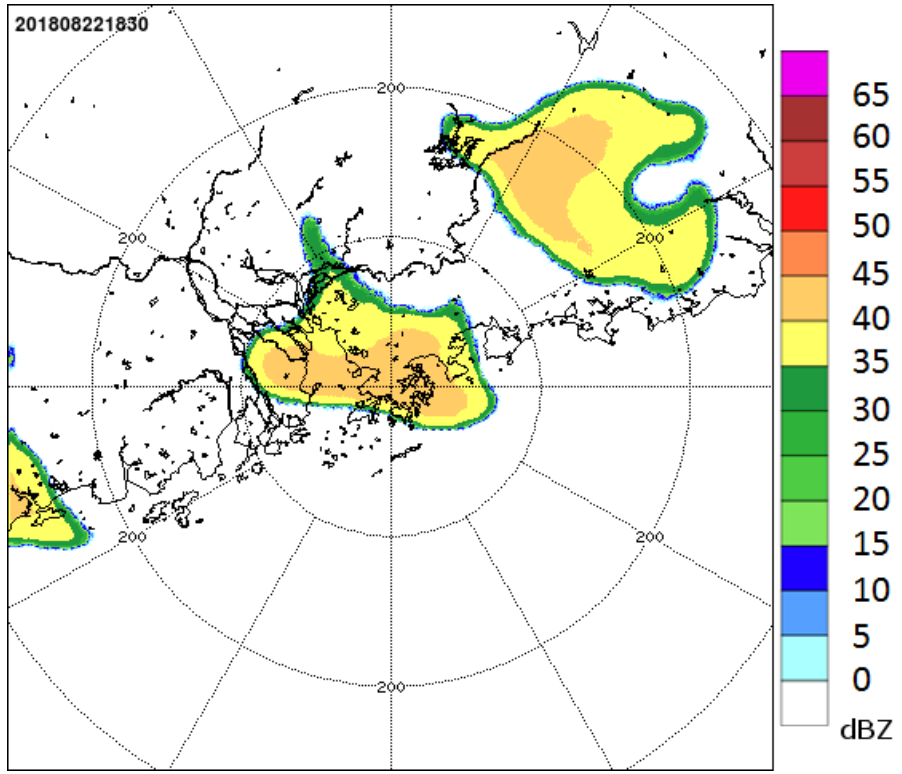
120-min Forecast Reflectivity
Based at 2018/08/22 16:30

Better capture growth and movement of radar echoes







Optical Flow (ROVER)

Actual

Deep Learn (TrajGRU)

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Satellite Nowcasting

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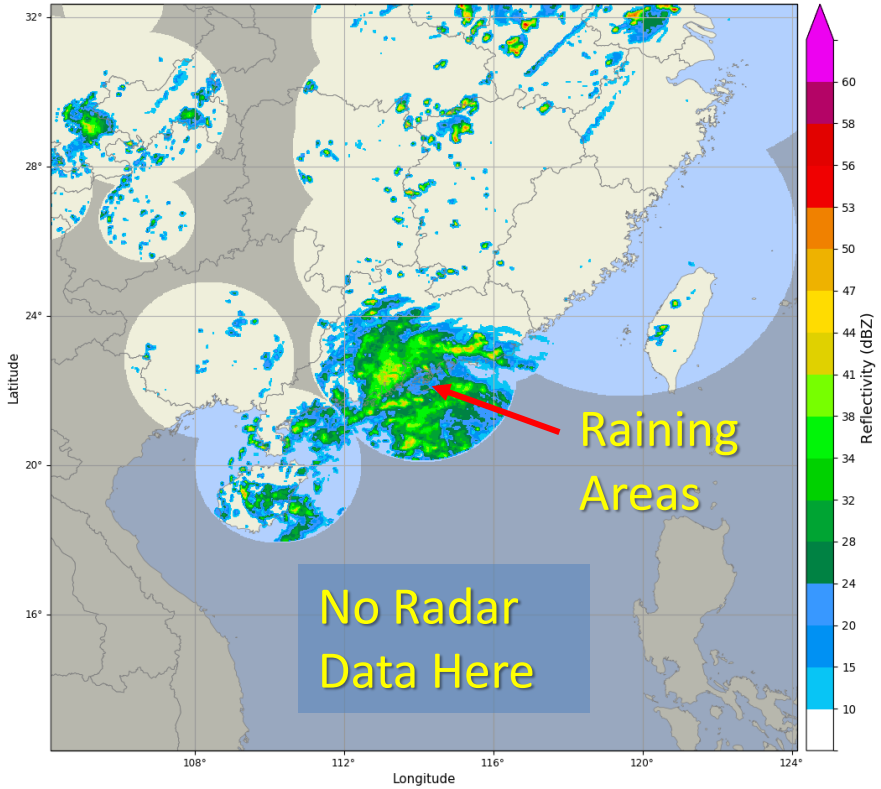
Retrieval of equivalent radar reflectivity using Himawari-8

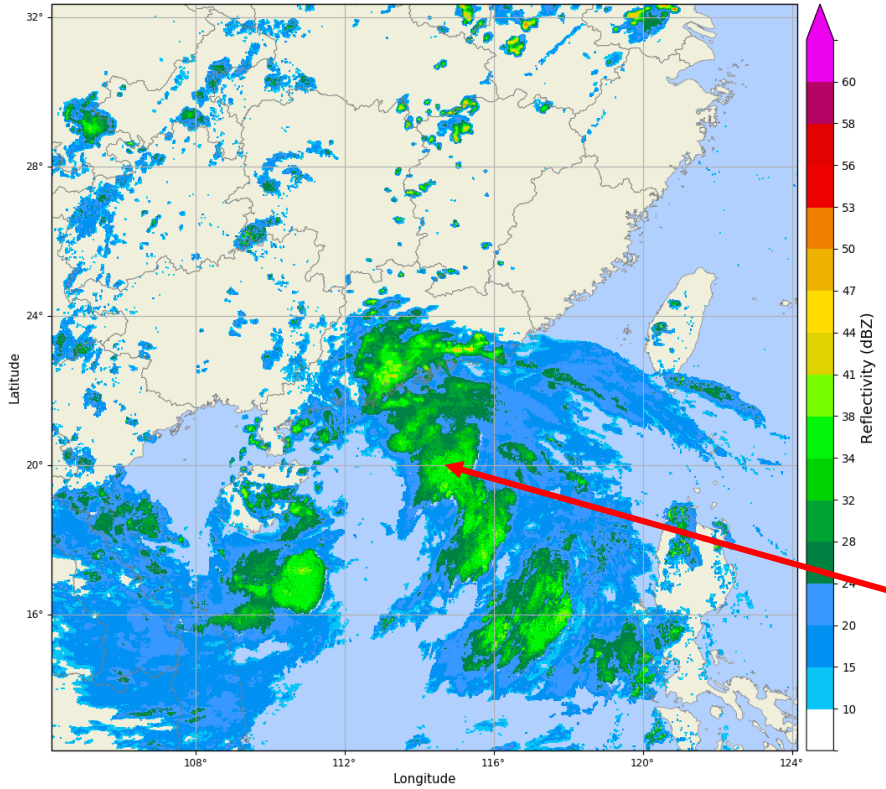
Reflectivity
CMA Radar / SC

2019-07-31 Based @ 15:00H
Valid @ 15:06H



Reflectivity
Multi-Sensor / SC

2019-07-31 Based @ 15:00H
Valid @ 15:06H



Raining Areas Far Away Simulated with Satellites' Data Using Our Neural Network

Spectral Information of Himawari-8 AHI

16 Bands of AHI (Advanced Himawari Imager)

MTSAT Channels	Band			Wavelength [μm]	Spatial Resolution	
	1	V1	Visible	0.46	1 km	RGB band composited
	2	V2		0.51	1 km	
VIS	3	VS		0.64	0.5 km	
	4	N1	Near Infrared	0.86	1 km	Aerosol
	5	N2		1.6	2 km	Water cloud and Ice cloud
	6	N3		2.3	2 km	Size of the cloud droplet
IR4	7	I4	Infrared	3.9	2 km	Fog, Hot spot (Forest fire)
IR3 (WV)	8	WV		6.2	2 km	Water vapor
	9	W2		7.0	2 km	
	10	W3		7.3	2 km	
	11	MI		8.6	2 km	SO_2 (Sulfur dioxide)
	12	O3		9.6	2 km	O_3 (Ozone)
IR1	13	IR		10.4	2 km	Atmospheric Windows
IR2	14	L2		11.2	2 km	
	15	I2		12.3	2 km	
	16	CO		13.3	2 km	CO_2 (Carbon dioxide)

Extracted from "Introduction to Himawari-8", JMA

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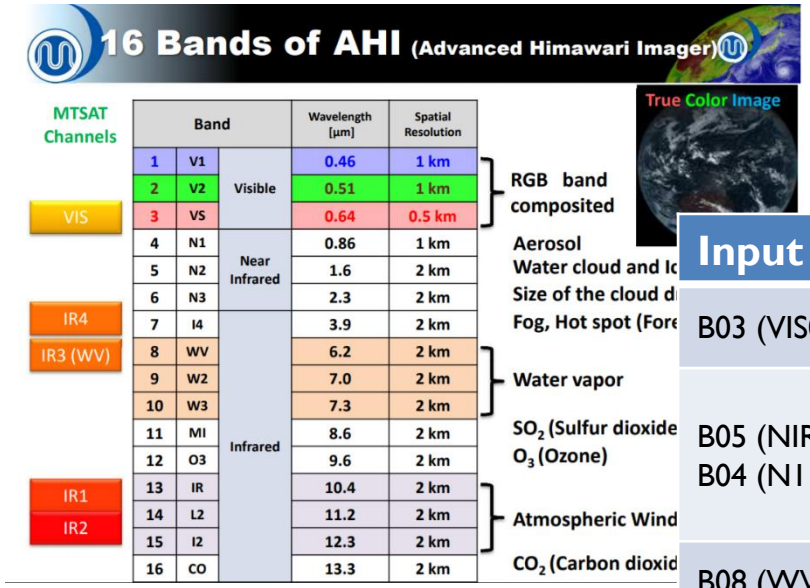
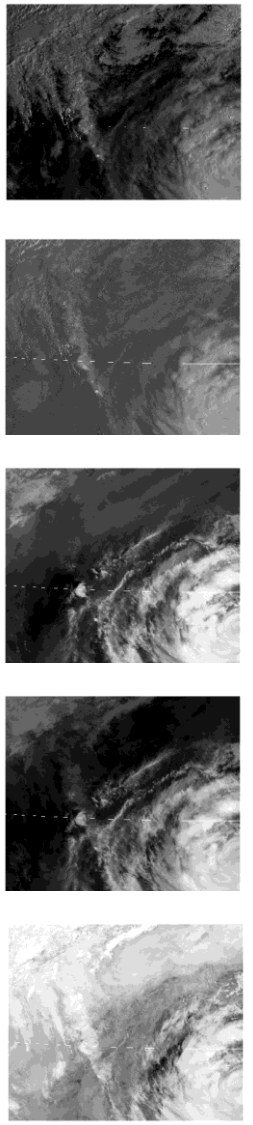
HONG KONG OBSERVATORY

Satellite Nowcasting



Band			Wavelength [μm]	Spatial Resolution
1	V1	Visible	0.46	1 km
2	V2		0.51	1 km
3	VS		0.64	0.5 km
4	N1	Near Infrared	0.86	1 km
5	N2		1.6	2 km
6	N3		2.3	2 km
7	I4	Infrared	3.9	2 km
8	WV		6.2	2 km
9	W2		7.0	2 km
10	W3		7.3	2 km
11	MI		8.6	2 km
12	O3		9.6	2 km
13	IR		10.4	2 km
14	L2		11.2	2 km
15	I2		12.3	2 km
16	CO		13.3	2 km

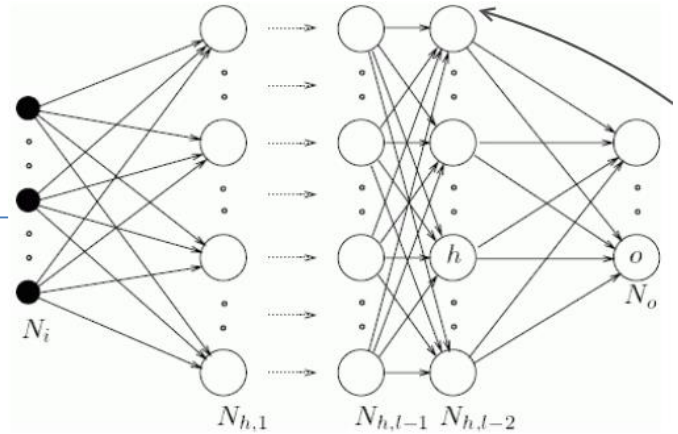
Input	Description
B03 (VIS0.64)	VIS0.64. Reflectivity of B03 depends on optical thickness. Thick cloud are displayed in white.
B05 (NIR1.6) - B04 (N1 0.86)	Difference between NIR1.6 and N1 0.86. B04 has high reflectivity for snow/ice covered area and clouds, sea surface looks dark. Reflection characteristic of B05 depends on the phase and size of cloud particles. On difference image, thick clouds with large ice particles are displayed in black (dark), low clouds and land/sea surface look whitish (bright)
B08 (WV6.2) - B10 (W3 7.3)	Difference between WV6.2 and W3 7.3. On difference image, thick clouds with high cloud are displayed in white, low clouds and thin Ci are indistinct.
B13 (IR10.4)	IR10.4, Atmospheric window band, available for 24 hours. High-level clouds and developed Cbs appear in white, mid-level cloud appear in bright gray.
B13 (IR10.4) - B15 (I2 12.3)	Difference between IR 10.4 and I2 12.3. Absorption by water vapor of B15 is slightly larger than that of B13. On difference image, thick cloud and low-level cloud contribute to rather grey color, high-level cloud contributes bright color.
Equinox day diff.	Indication of different Season

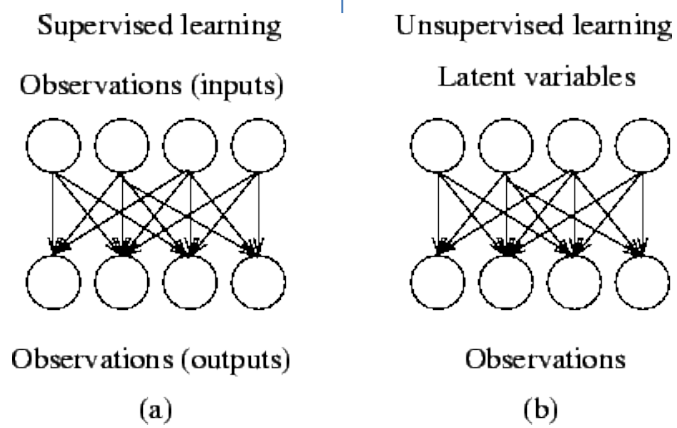


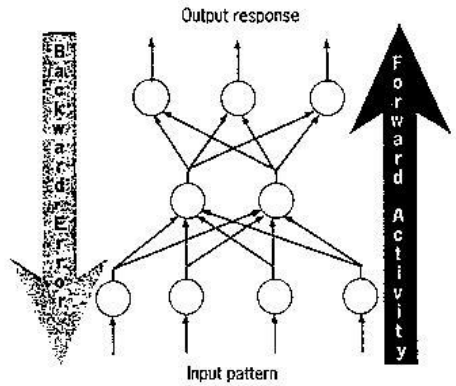
Multi-layer perceptron artificial neural network (MLPANN)

- Features of MLPANN implemented in HKO:

Neural Network Architecture	Deep neural networks
Training Algorithm	Backpropagation
Learning Strategy	Supervised learning







A backpropagation network trains with a two-step procedure. The activity from the input pattern flows forward through the network, and the error signal flows backward to adjust the weights.

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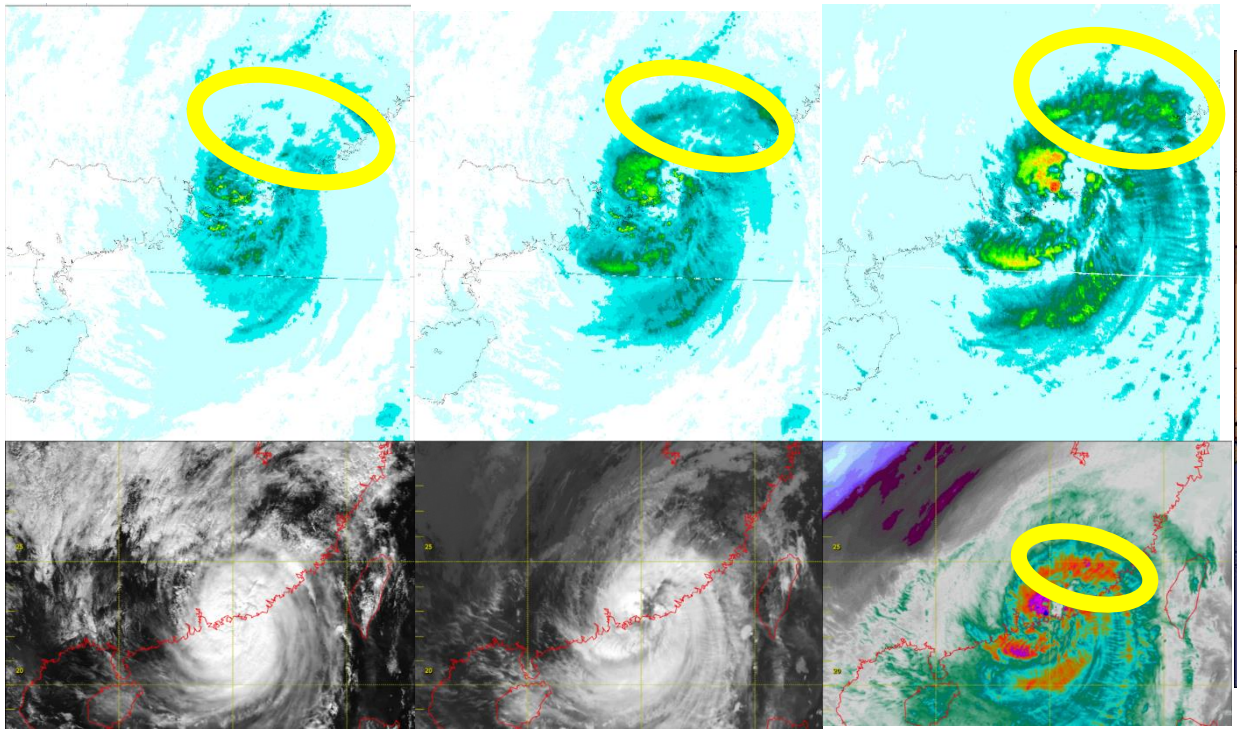
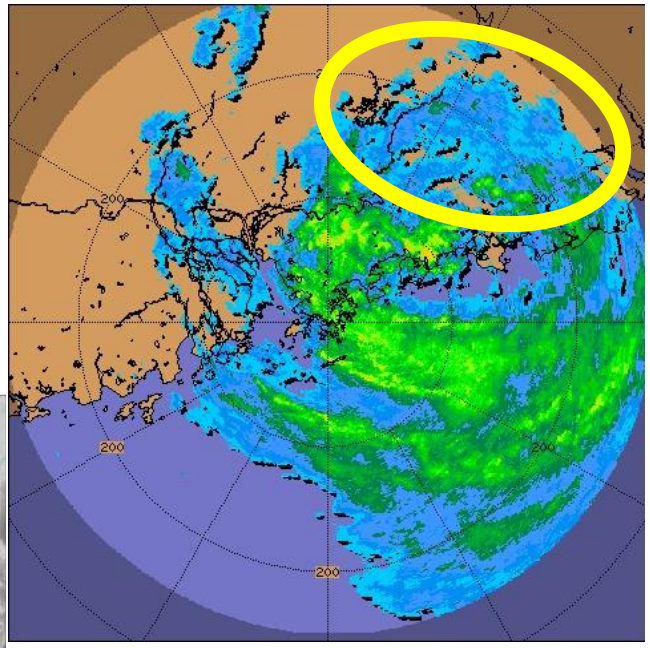
Compare with Available Satellite Product

With-VIS Mode | Blend Mode | Without-VIS Mode



Visible | IR1 | WV

2016 Typhoon Haima
20161021 UTC0400



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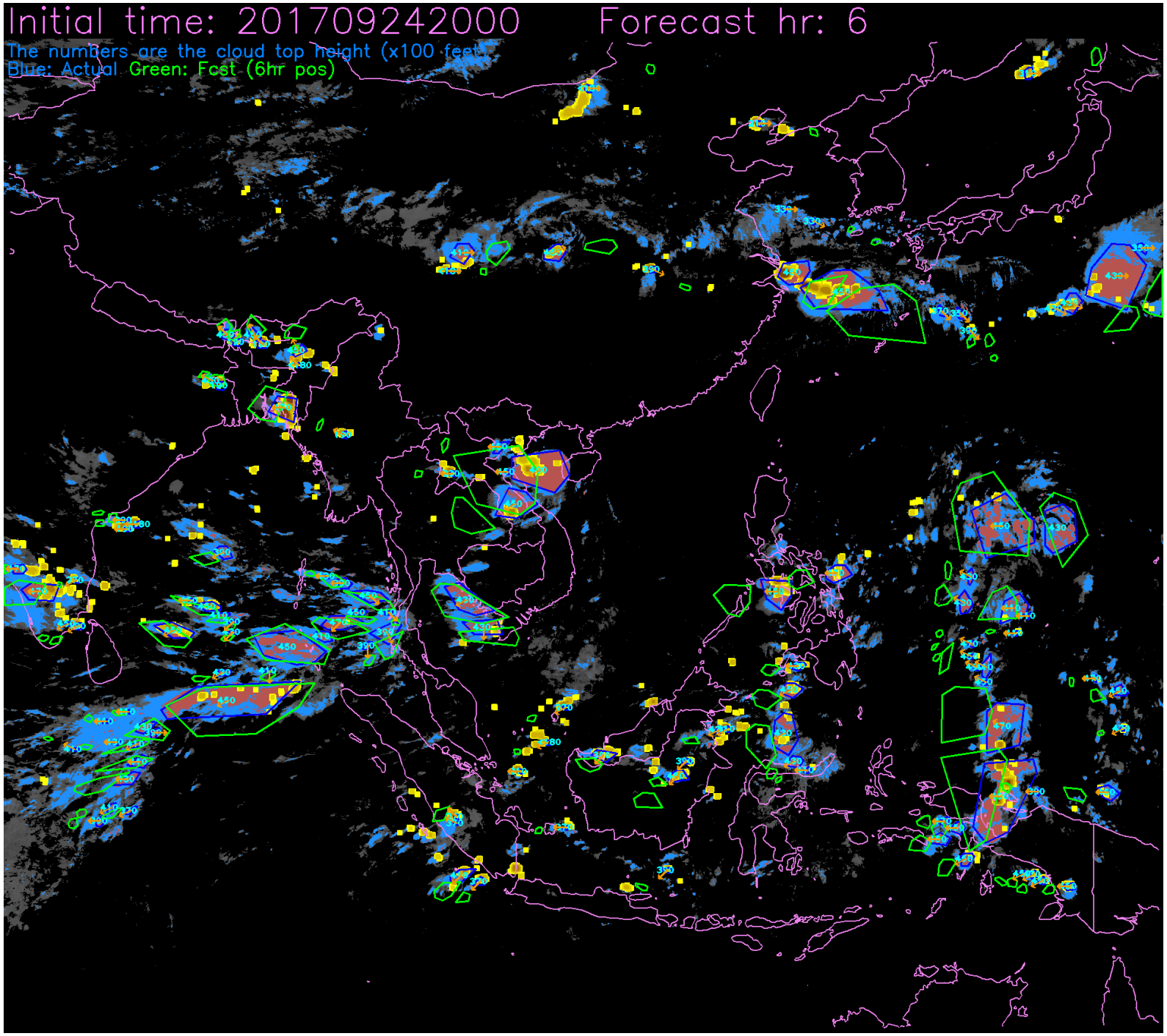
Significant Convection Nowcast using Himawari-8 retrieved reflectivity available in real-time on HKO's RSMC for Nowcasting website



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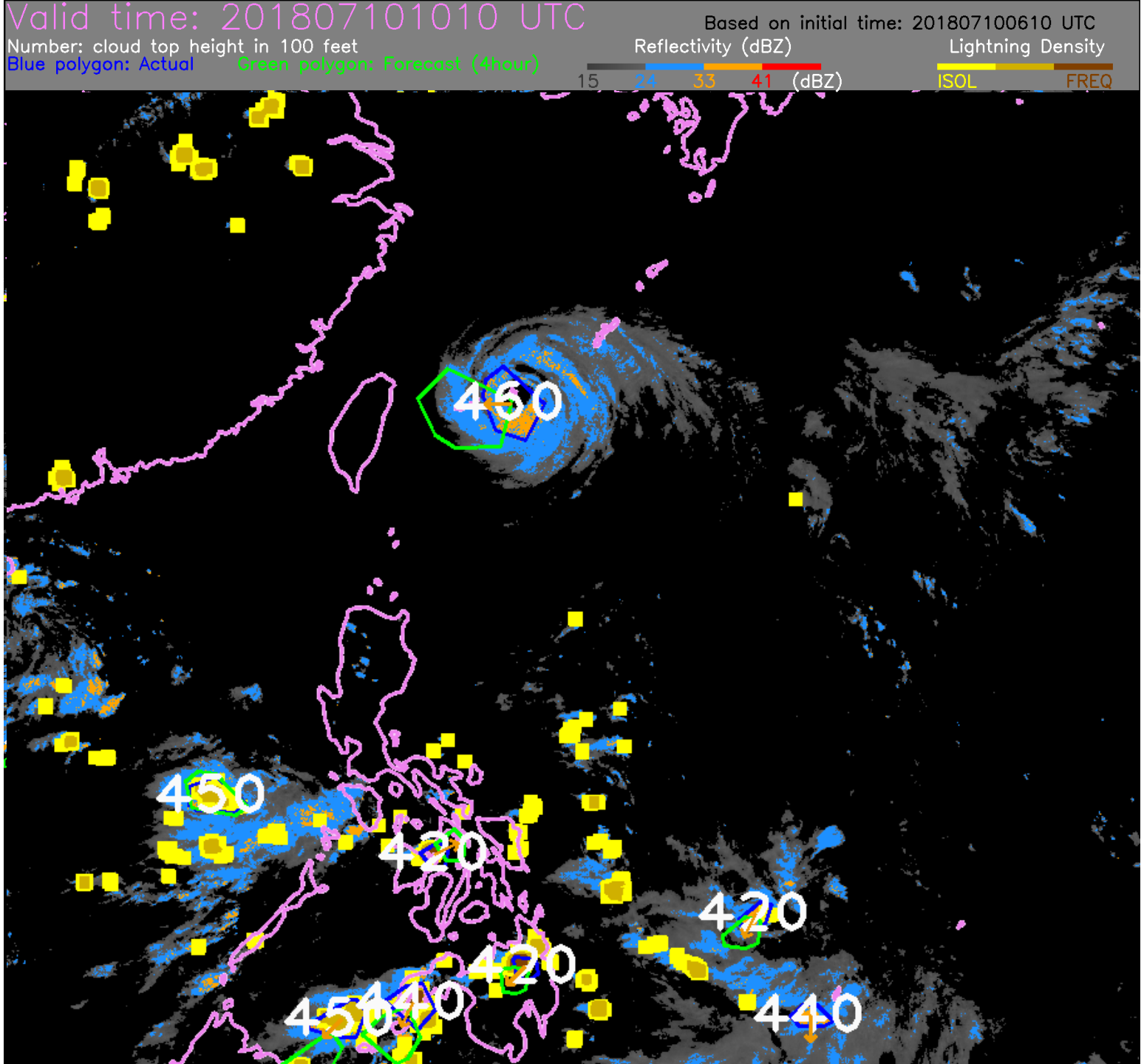
- Significant Convection Nowcast
  - 0-6 hour nowcast
  - Retrieved reflectivity from Himawari-8
  - Composite imagery with GDL360 lightning density (yellow/brown)
  - Fengyun-4 under development



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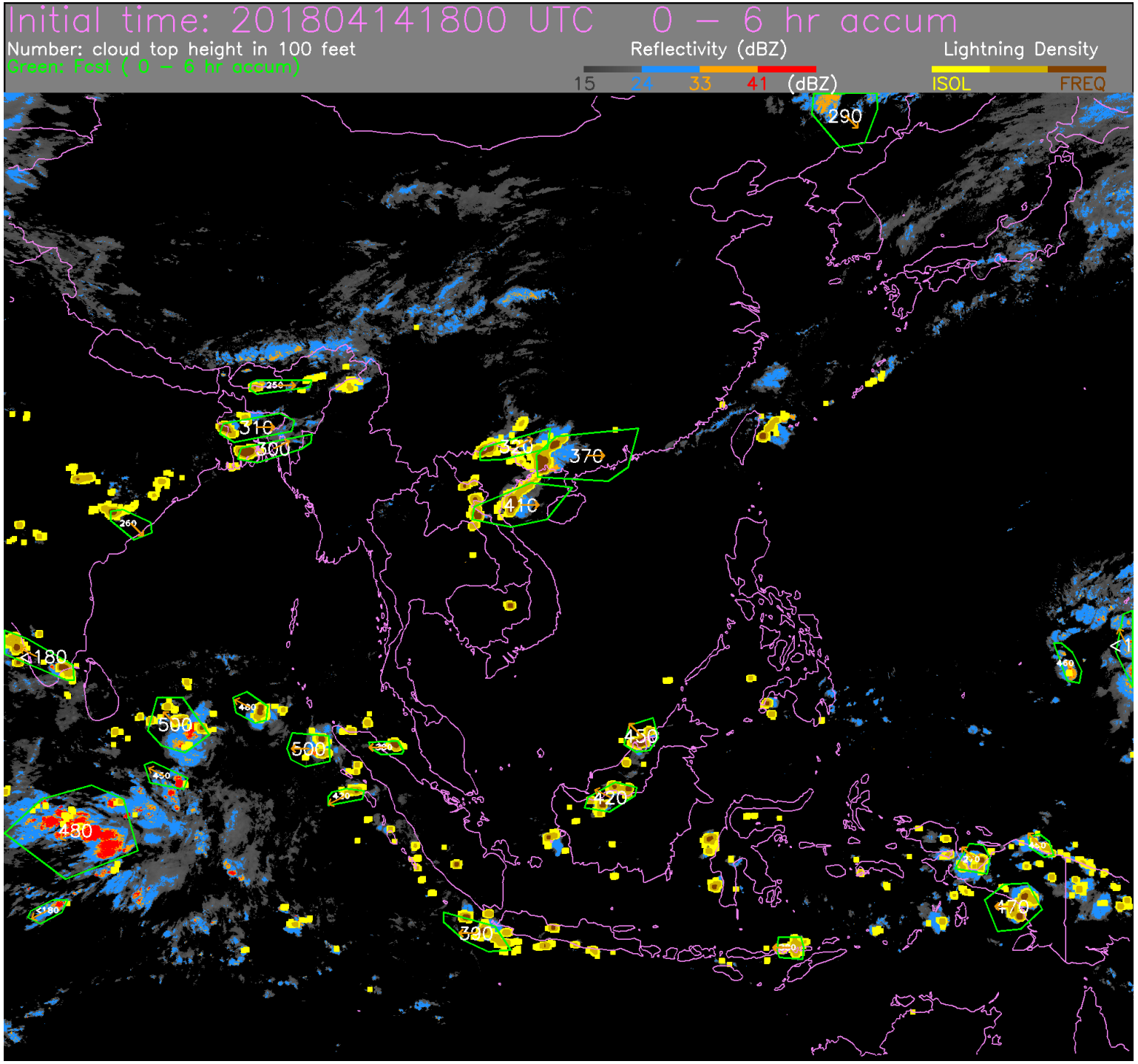
15 Apr 2018

0-6 hr nowcast from
18:00 UTC



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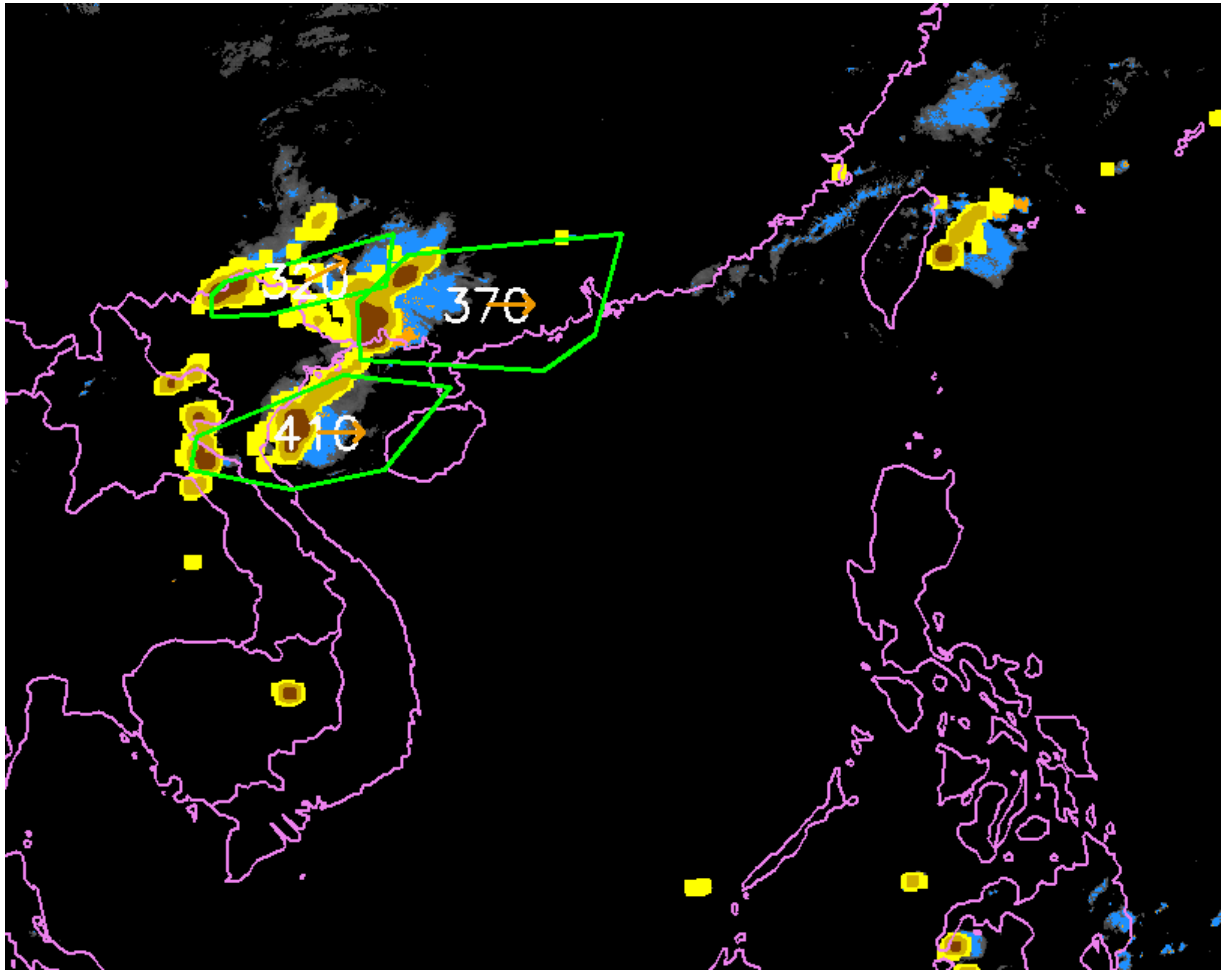
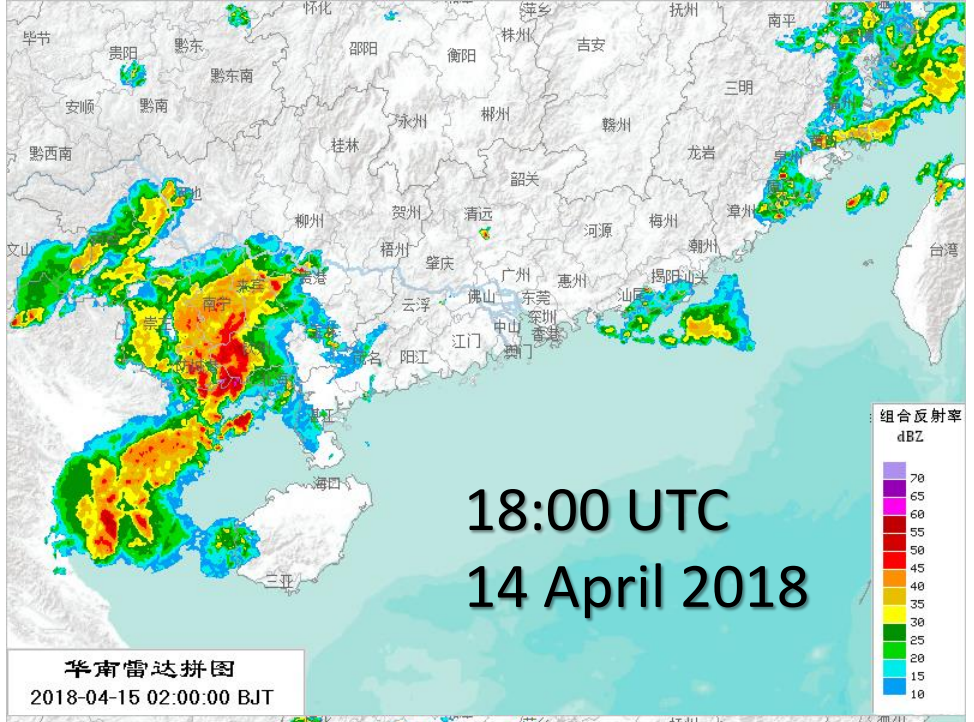
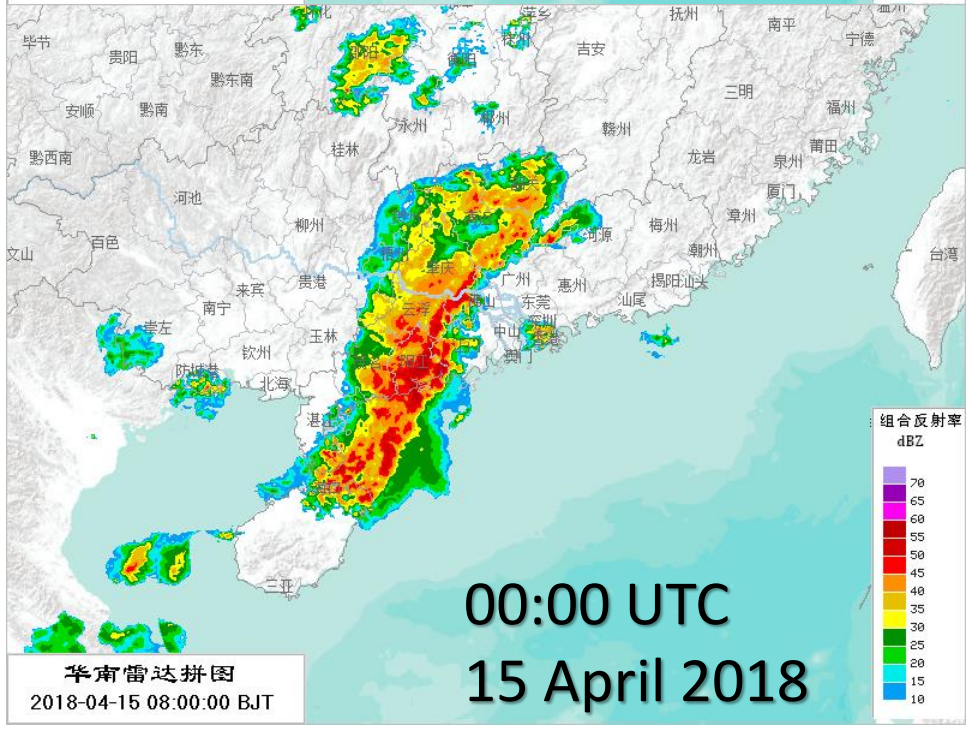
0-6 hr nowcast from 18:00 UTC







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Thank You!

THE END