Nowcast of Thunderstorm, Hail and Gust Satellite Nowcast Applications

WC Woo, Hong Kong Observatory

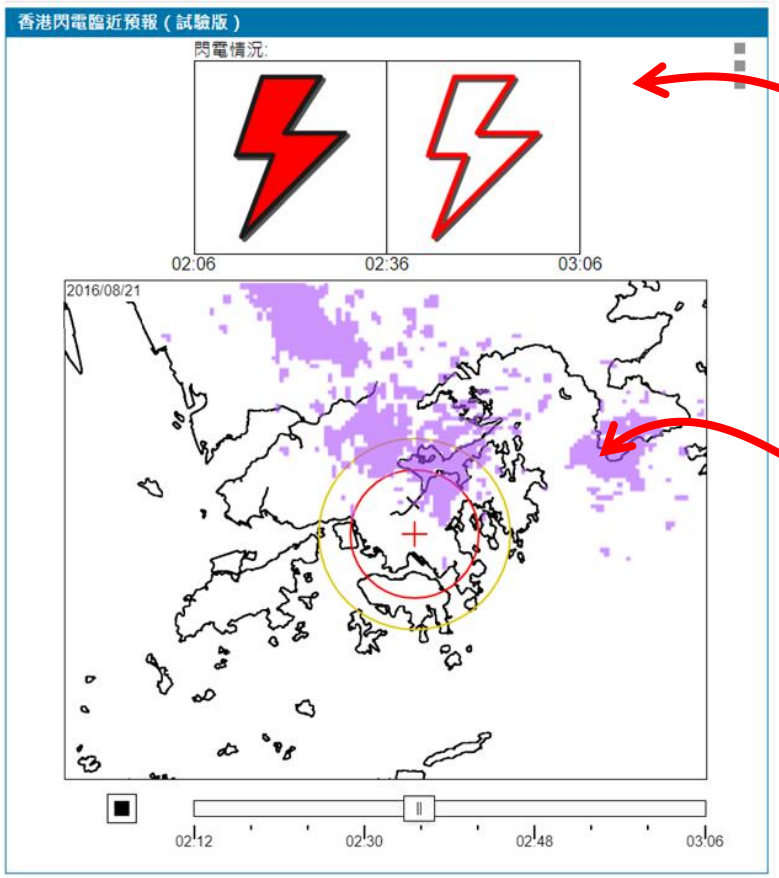
Typhoon Committee Roving Seminar 2019

Beijing, China

12 November 2019

Nowcast of Thunderstorms

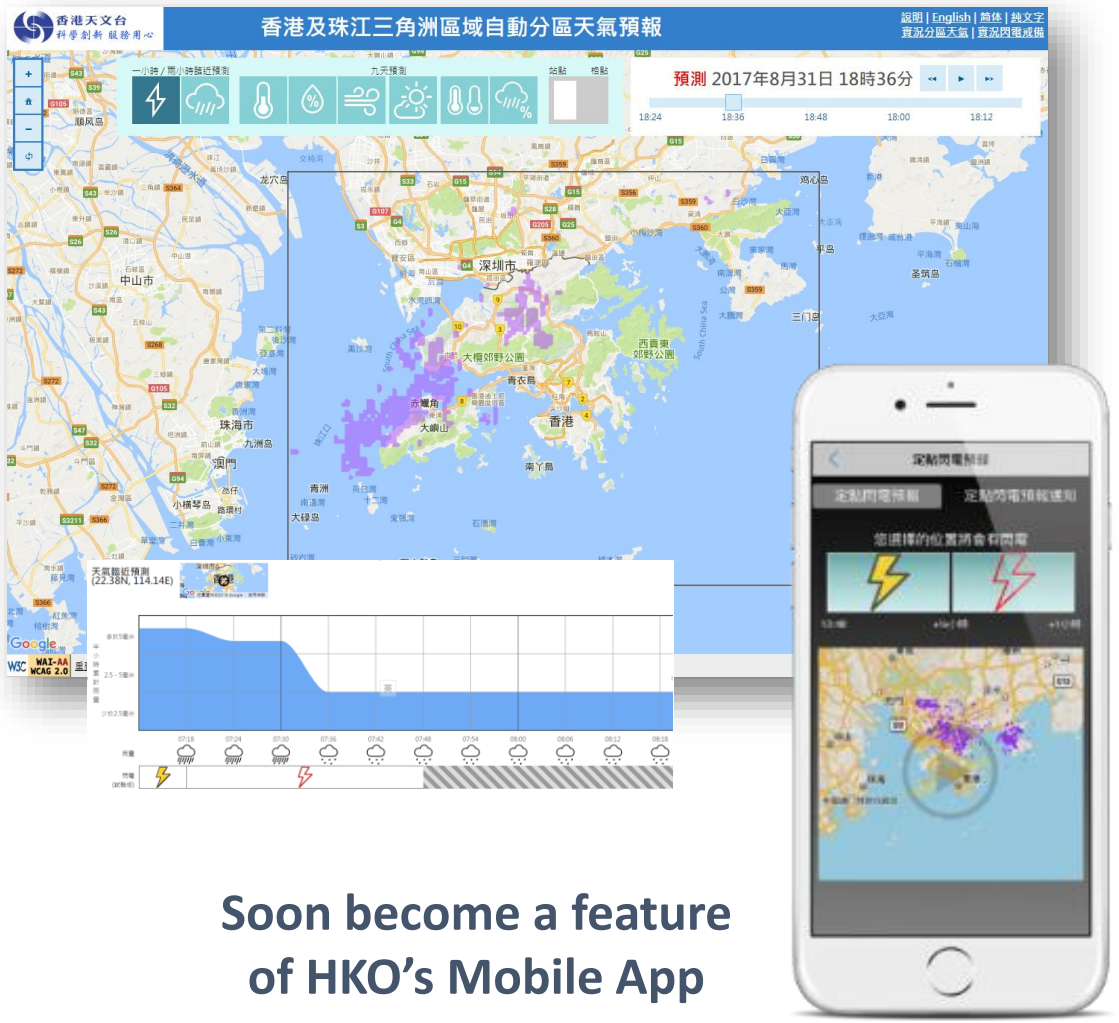
One-Hour Lightning Nowcast of HKO



Lightning Alerts

Predicted Lightning Distribution

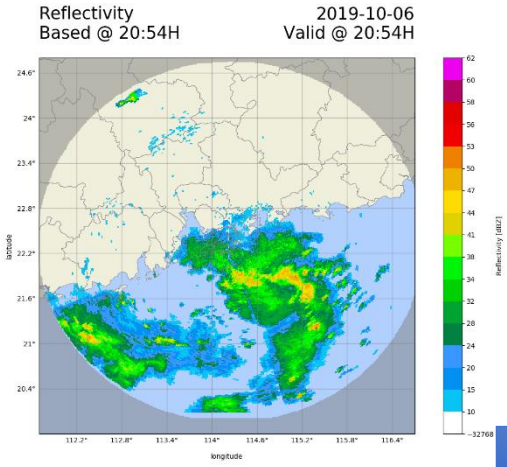
Automatic Regional Weather Forecast



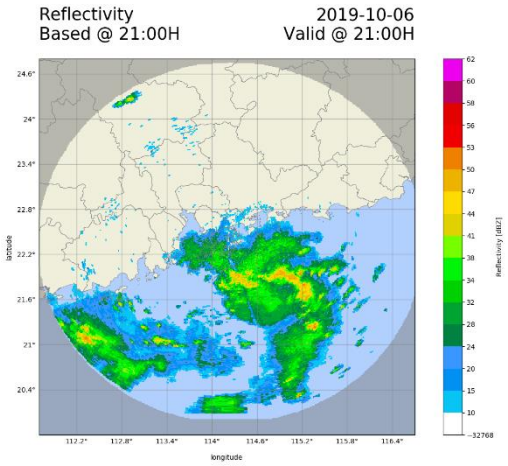
Soon become a feature of HKO's Mobile App

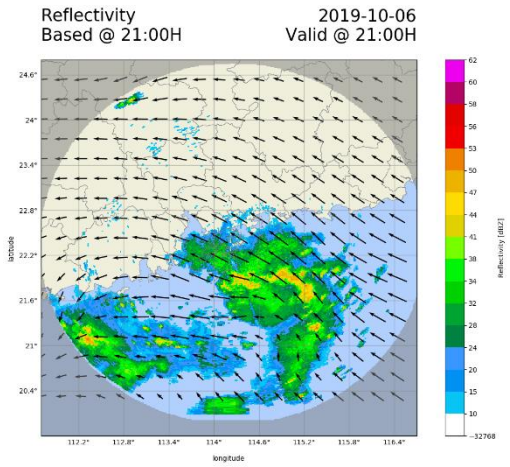
Lightning Nowcast by Extrapolation

6 Minutes Earlier



Latest





Motion Field

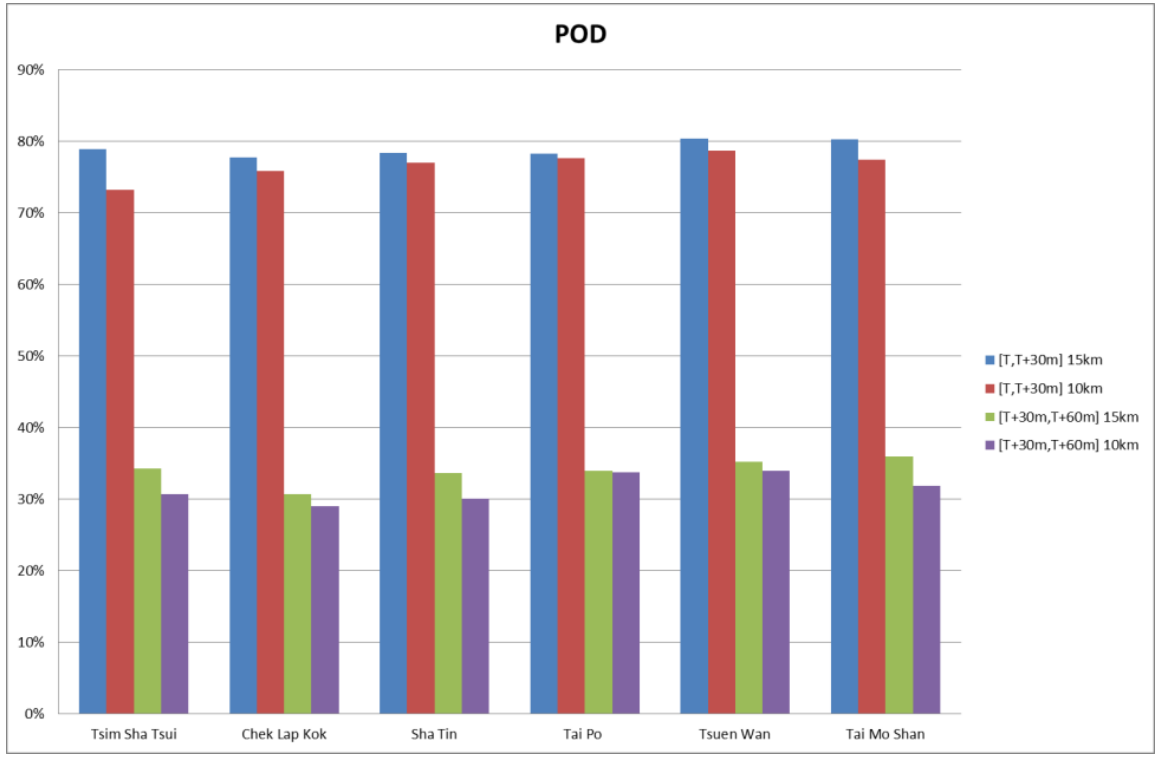
<u>Steps:</u>

1. Calculate Motion Field from Recent Radar Images
2. Extrapolate Detected Lightning Locations to Produce Lightning Nowcast
3. Alert if the Predicted Lightning Locations fall within 10 / 15 km of the User

Performance of Lightning Nowcast

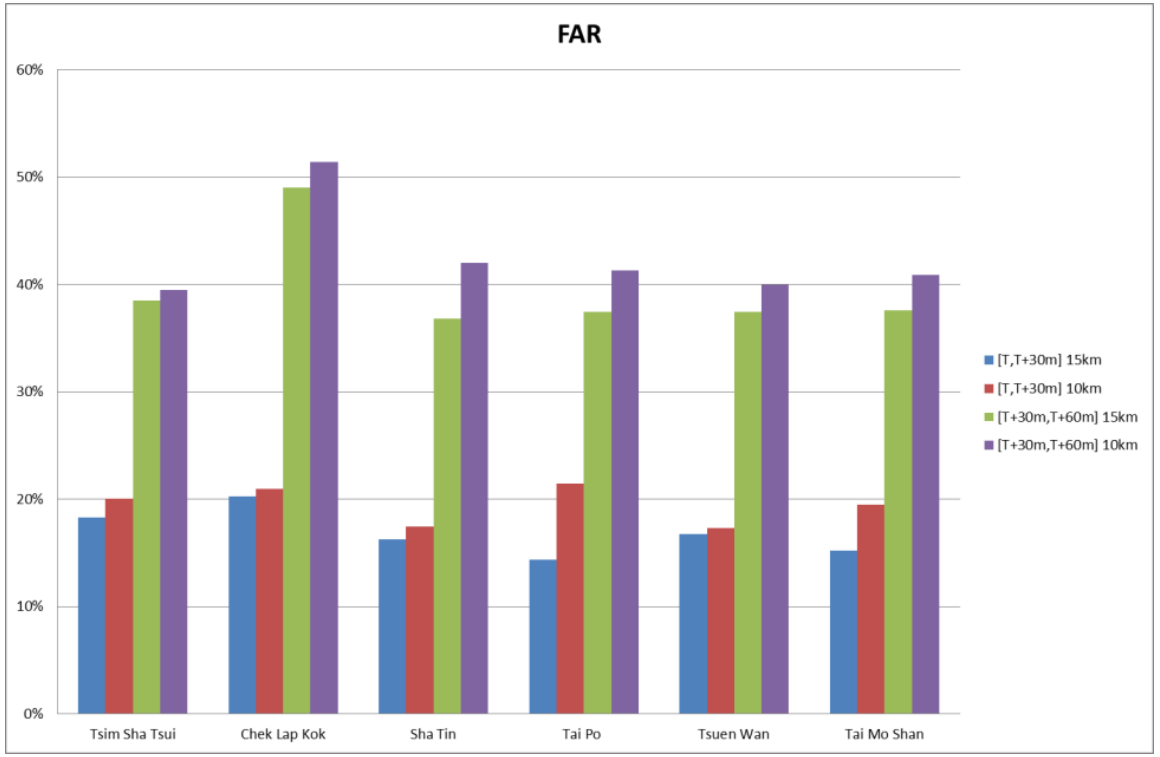
For first half-hour 15 km

POD is around **70**-80%



For first half-hour 15 km

FAR is around 15-**20**%



Lightning Initiation

Simple Conceptual Model

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

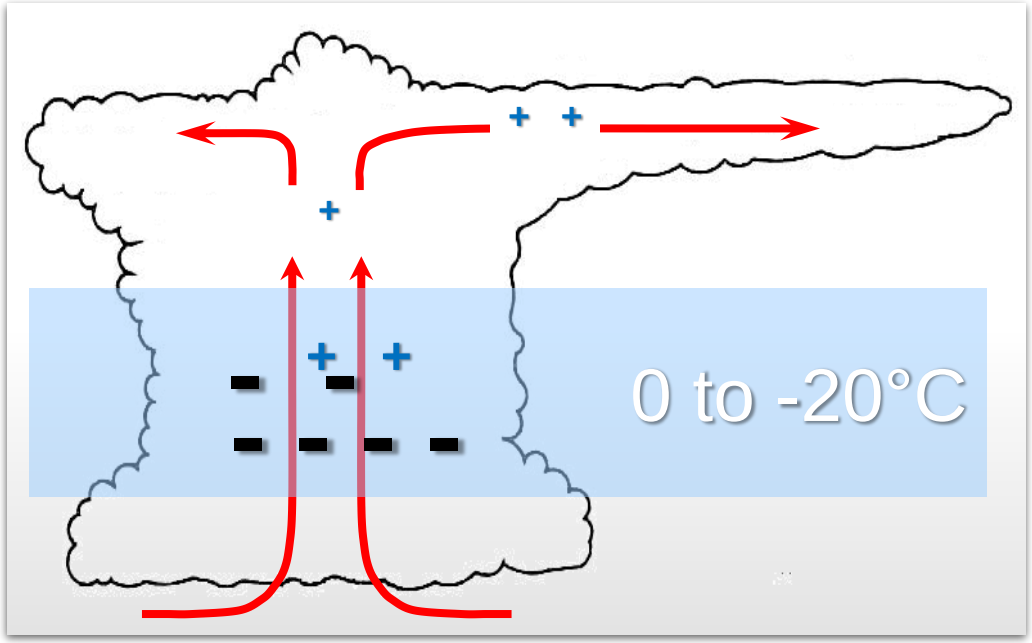


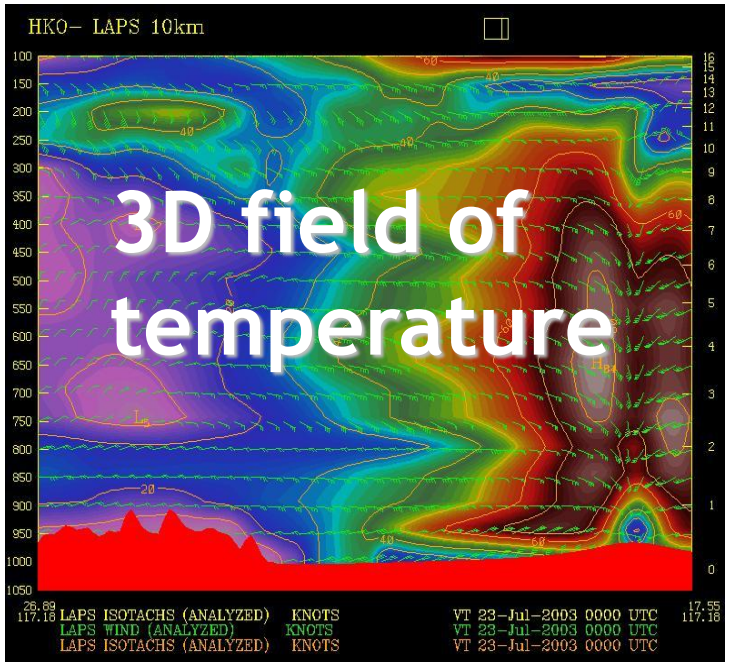
Table II – Summary of the conceptual model for lightning initiation.

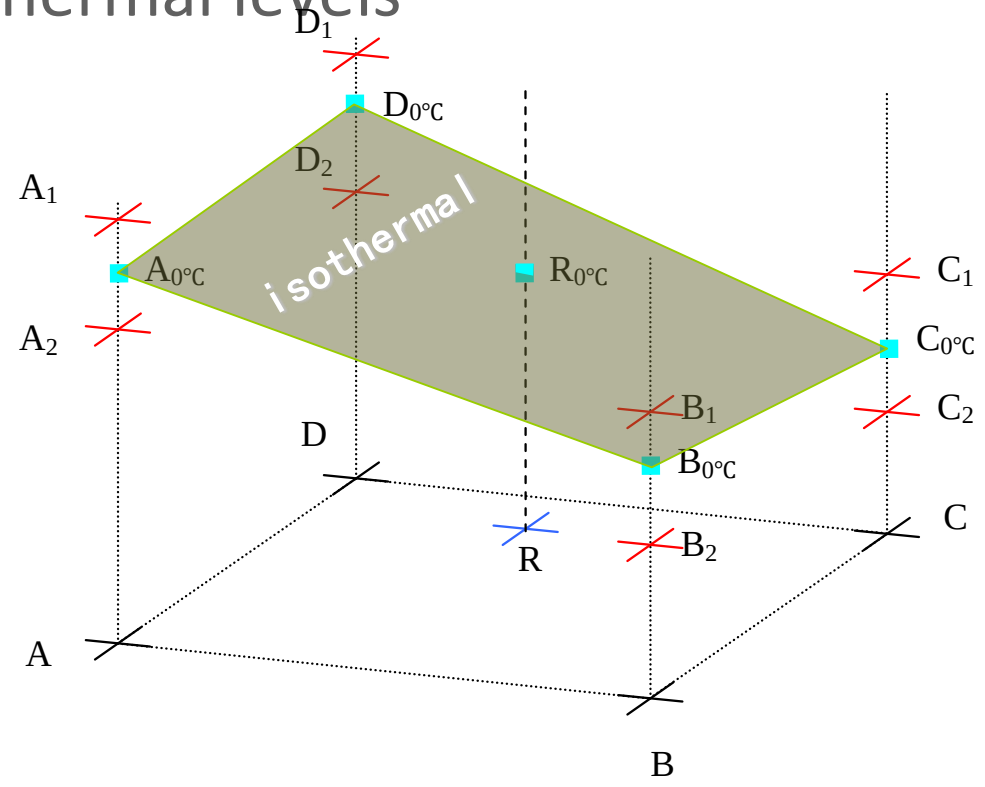
Isothermal Layers	(i) Shallow Cu			(ii) Towering Cu			(iii) mature Cb			(iv) decaying Cb		
	D	H	E	D	H	E	D	H	E	D	H	E
below –40°C							⇑	*	ρ	⇑	*	ρ
–20 to –40°C				⇑	*	ρ	⇑	*	ρ	⇑	*	
–10 to –20°C	⇑	*		⇑⇓	* △	σ	⇑⇓	* △	σ		*	
0 to –10°C	⇑	💧		⇑	* 💧		⇑⇓	* △ 💧	σ		*	
above 0°C	⇑	💧		⇑	💧		⇑⇓	△ 💧	σ	⇓	△	
near surface	→←			→←			← →			← →		

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.

Isothermal Reflectivity

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



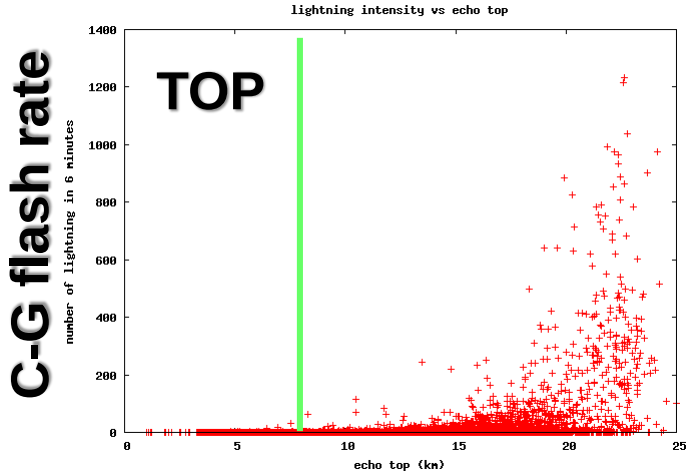


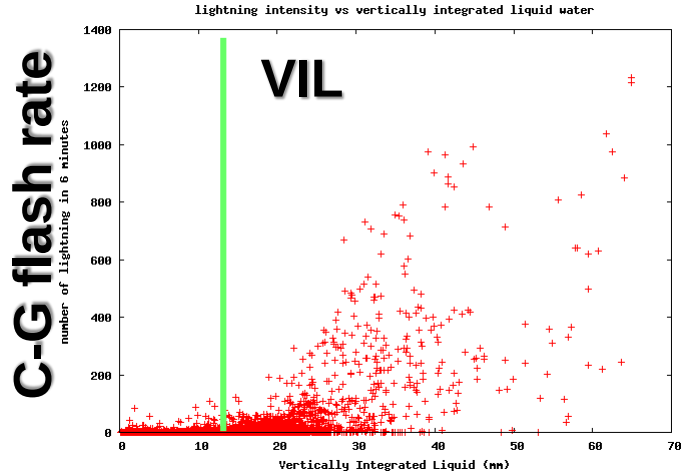
Lightning Predictors

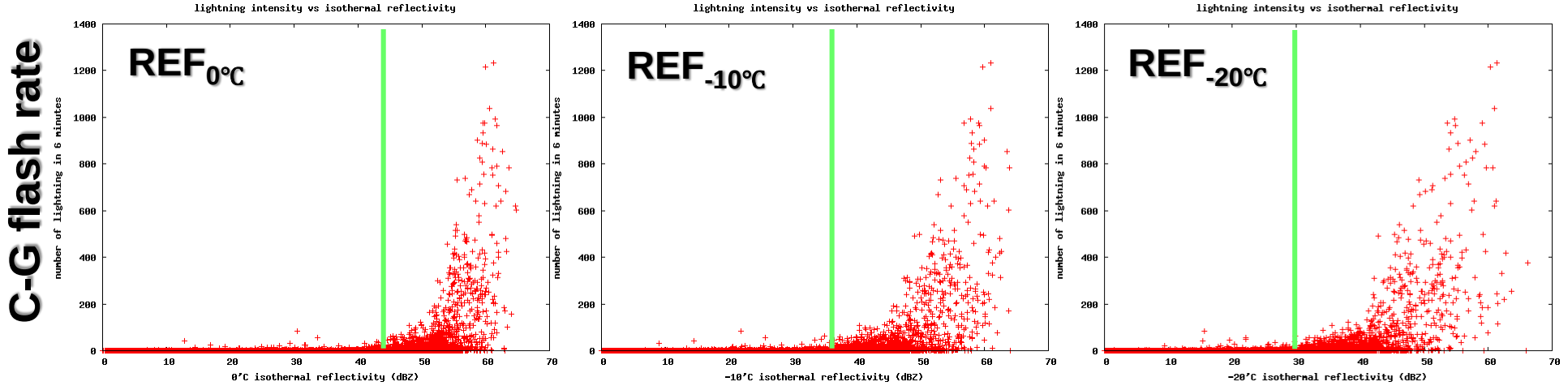
- lightning physics reflected in radar observations:
  - TOP (updraft)
  - VIL (overall liquid content)
  - $REF_{0°C}$
  - $REF_{-10°C}$
  - $REF_{-20°C}$

  } (super-cooled liquid, water-coated graupel)
- consider lightning initiation as an on-off process
- also used in lightning severity (log flash rate) prediction

Lightning as an On-Off Process







Thresholds under Testing

- good indicators of the onset of C-G lightning in 15-20 minutes with high CSI:
  - TOP > 7.6 km
  - VIL > 5.9 mm
  - $REF_{0°C}$ > 47 dBZ
  - $REF_{-10°C}$ > 17 dBZ
  - $REF_{-20°C}$ > 0 dBZ
- may gain a bit longer lead time by lowering the thresholds

Lightning Intensity

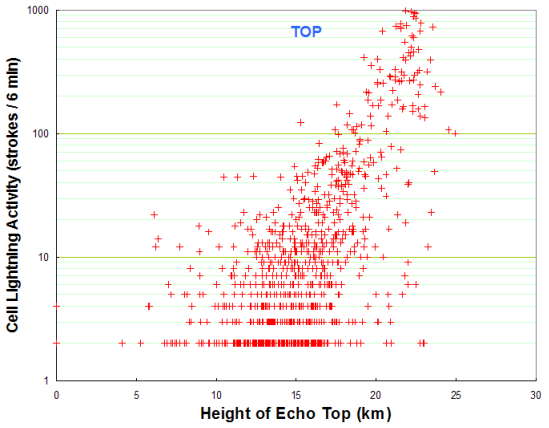
- define lightning severity:

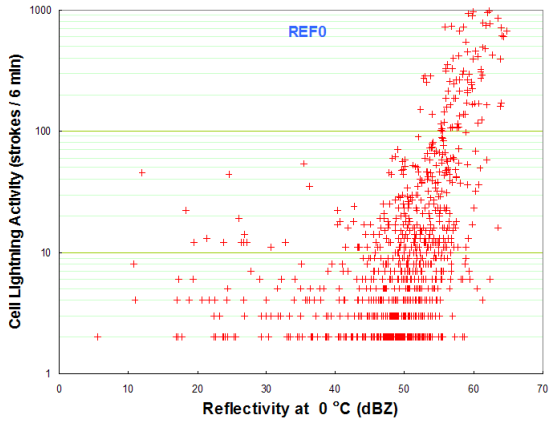
$$\zeta = \log_{10}(\alpha)$$

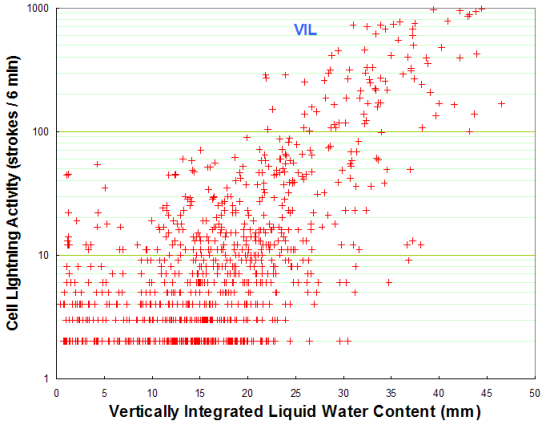
  - where α is the number of CG lightning strokes in 6 minutes associated with a storm cell

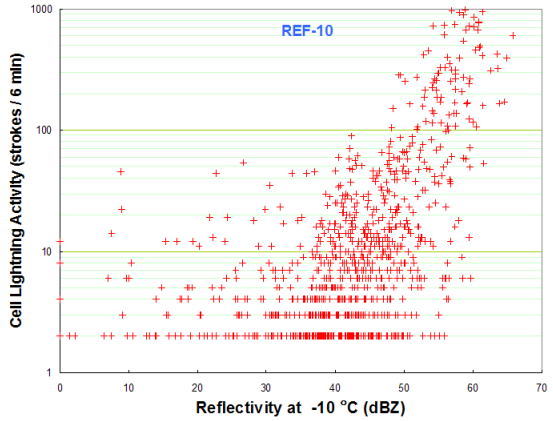
- linear relationships:

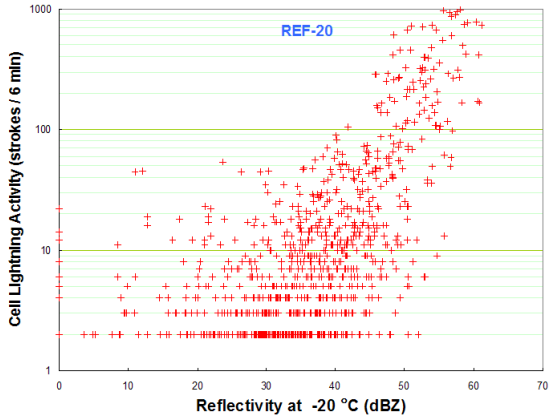
$$\zeta = a + \sum b_i \cdot x_i$$











Preliminary Results

- predicted severity:

$$\zeta = -3.623\times10^{-01} + 6.105\times10^{-02}\times TOP(km) + 2.601\times10^{-02}\times VIL(mm) + 1.967\times10^{-06}\times REF_{-20℃}(Z) + 1.146\times10^{-07}\times REF_{0℃}(Z)$$

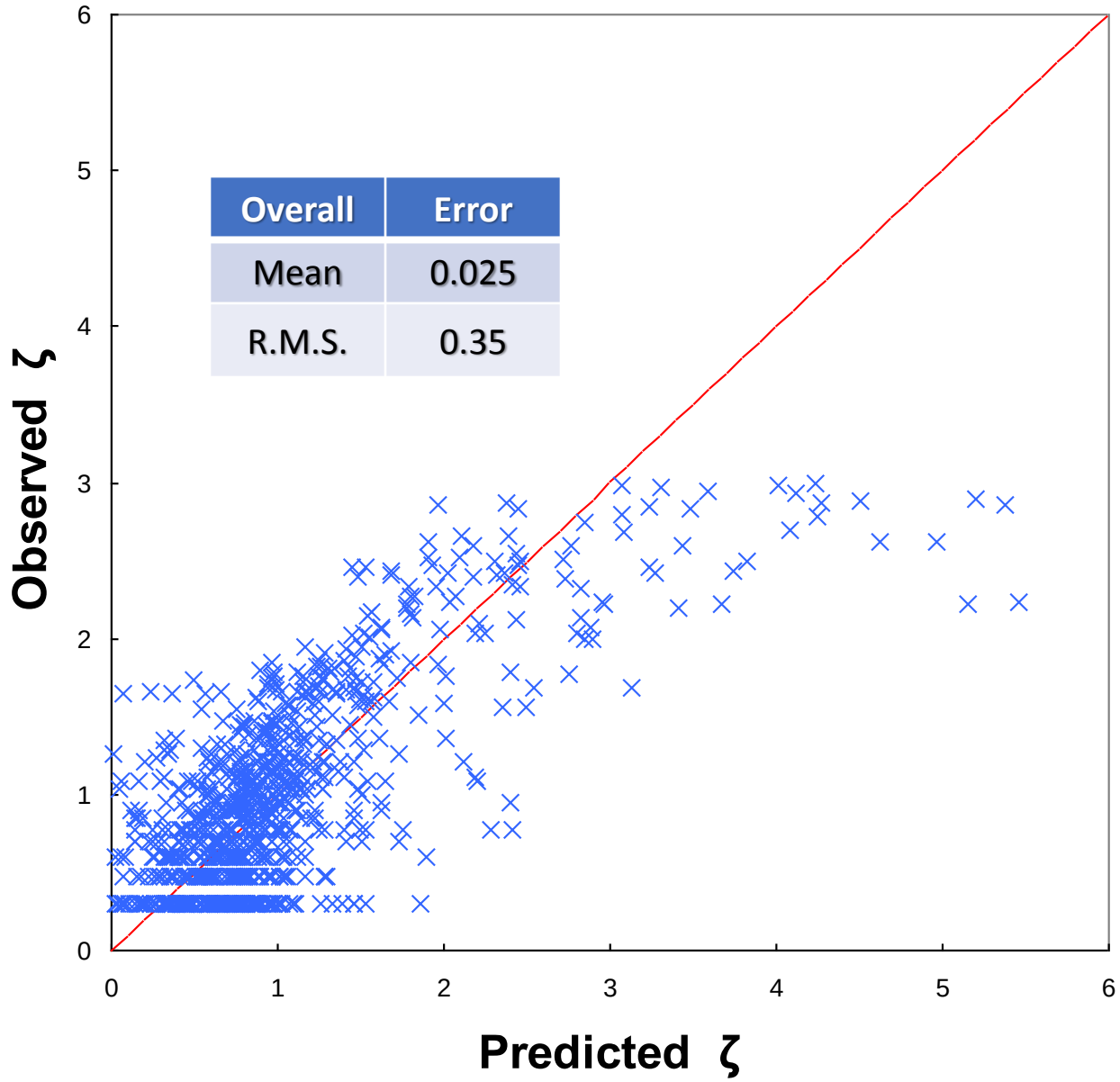
- coef. normalized:

$$\beta_{TOP} = 0.273$$

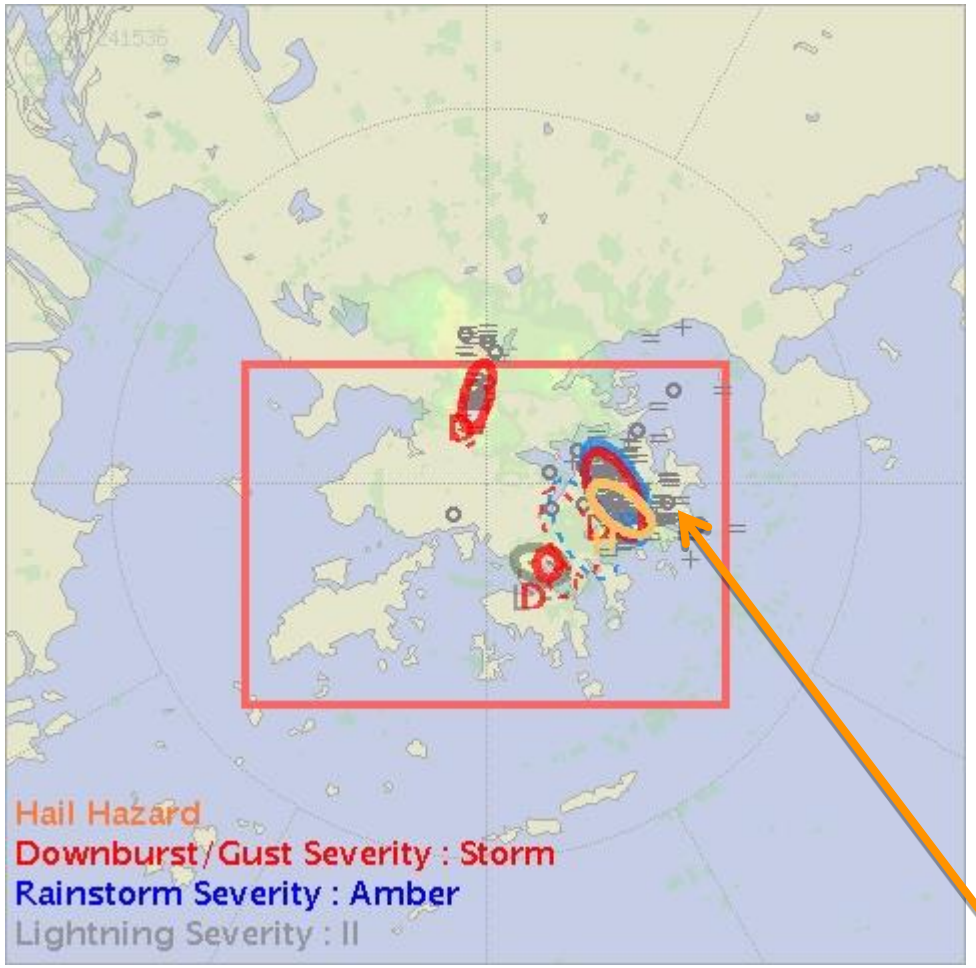
$$\beta_{VIL} = 0.387$$

$$\beta_{Z_0} = 0.037$$

$$\beta_{Z_{-20}} = 0.273$$



Lightning Initiation Nowcast



- hailstorm in Hong Kong on 24 July 2006
- first CG lightning alert issued at 3:00 pm
  - *see gray ellipse inside the red rectangular warning zone*
- CG lightning first detected ("=" symbols) during 3:12-3:18 pm
  - *threat areas for downburst/severe gust and heavy rain are marked by red and blue ellipses respectively*

03:36 pm

lead time = 12 min

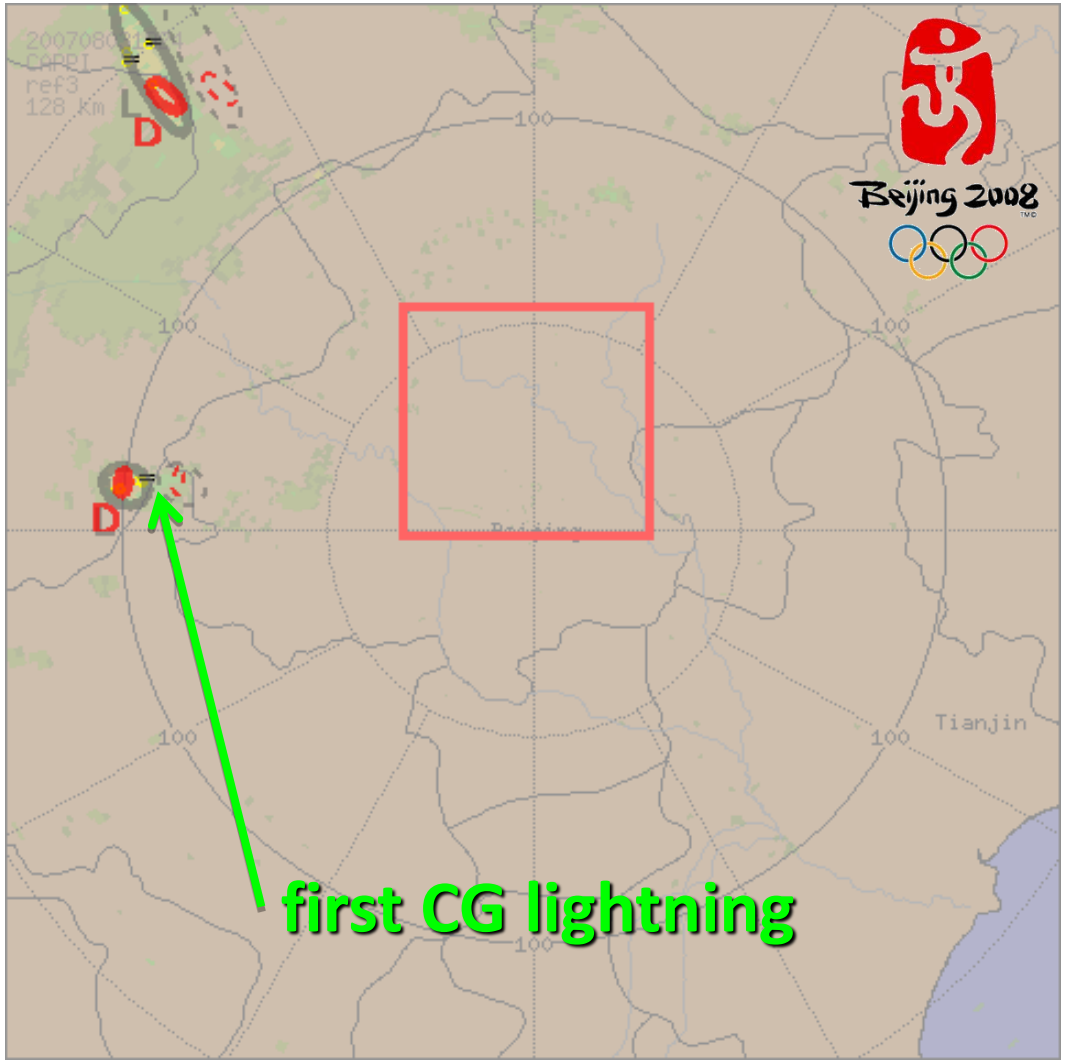
first CG lightning

Lightning Nowcasts for Beijing

- isolated thunderstorm west of Beijing city on 3 August 2007
- first CG light alert issued at 5:48 pm
- CG lightning first detected ("=" symbols) during 6:18-6:24 pm

06:24 pm

lead time = 30 min

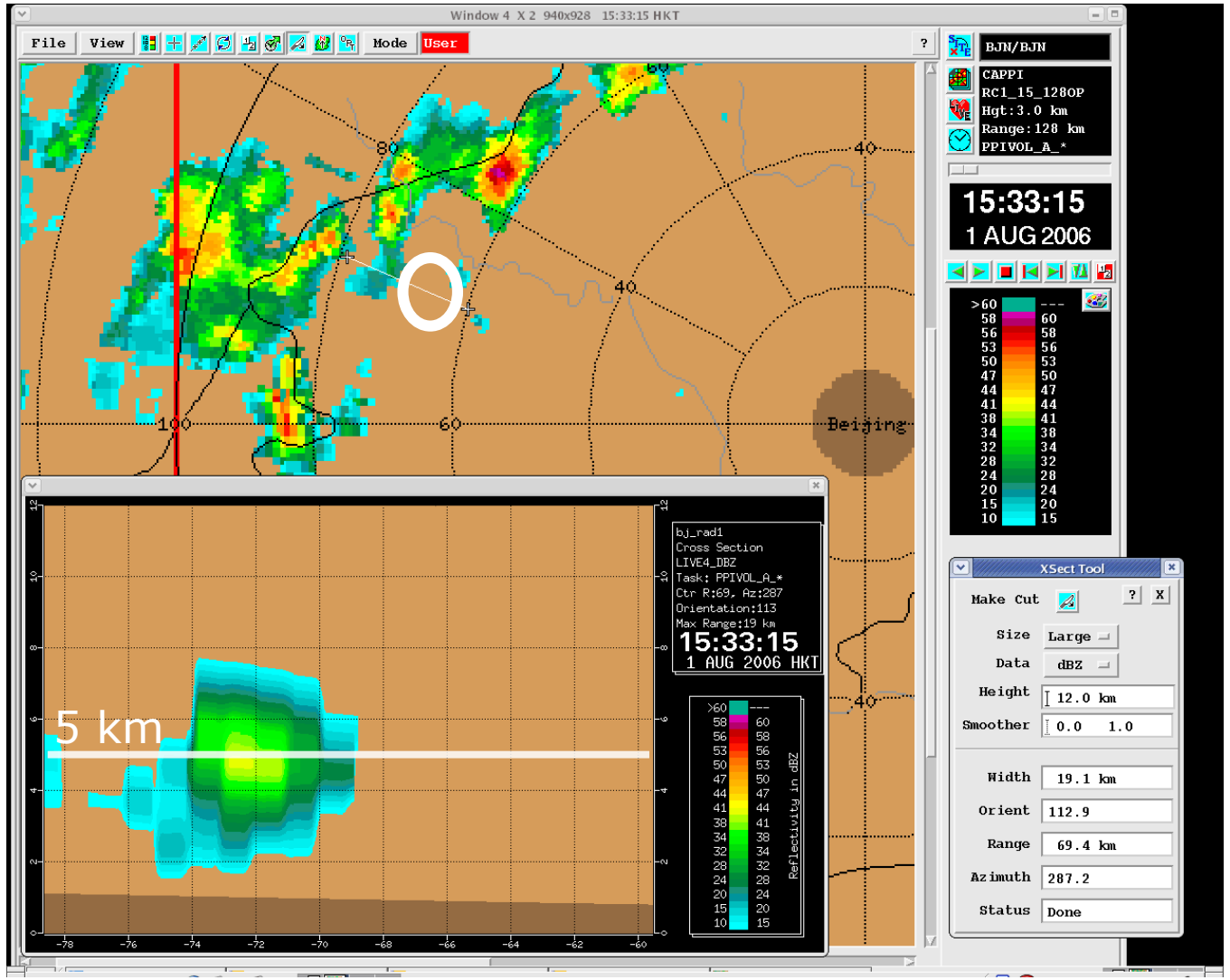


Nowcast of Gust

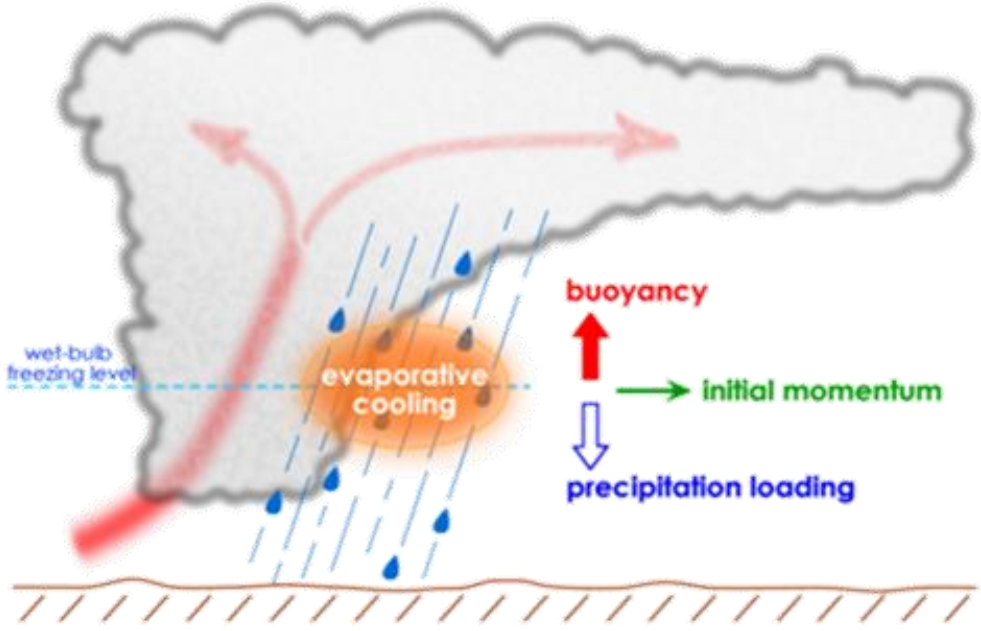
Thunderstorm Downburst as Seen from Radar

- building up of precip. core at mid levels
- precip. core descending → downburst
- occurring at time scale of a few minutes
- severe wind gust on ground

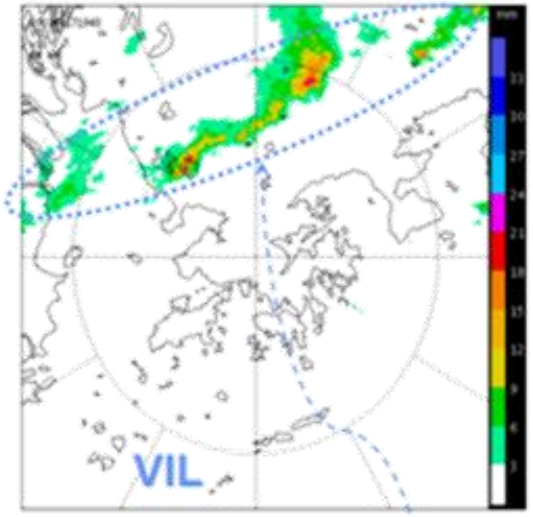
  ⇒ *Downburst/squalls*



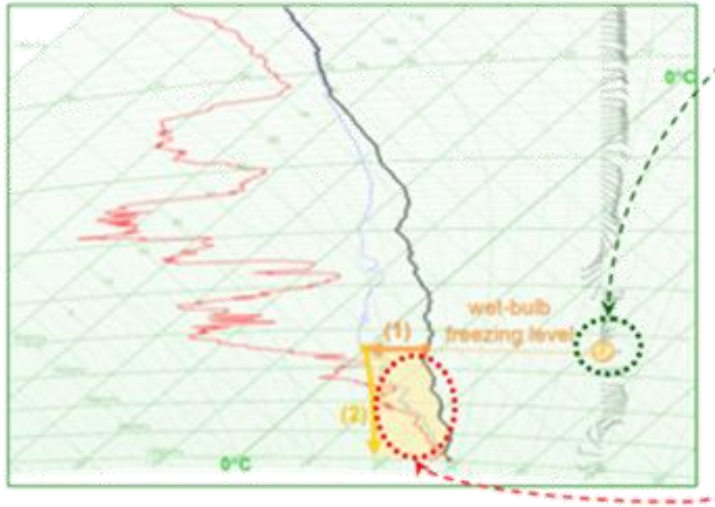
Simple Downburst Conceptual Model



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



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



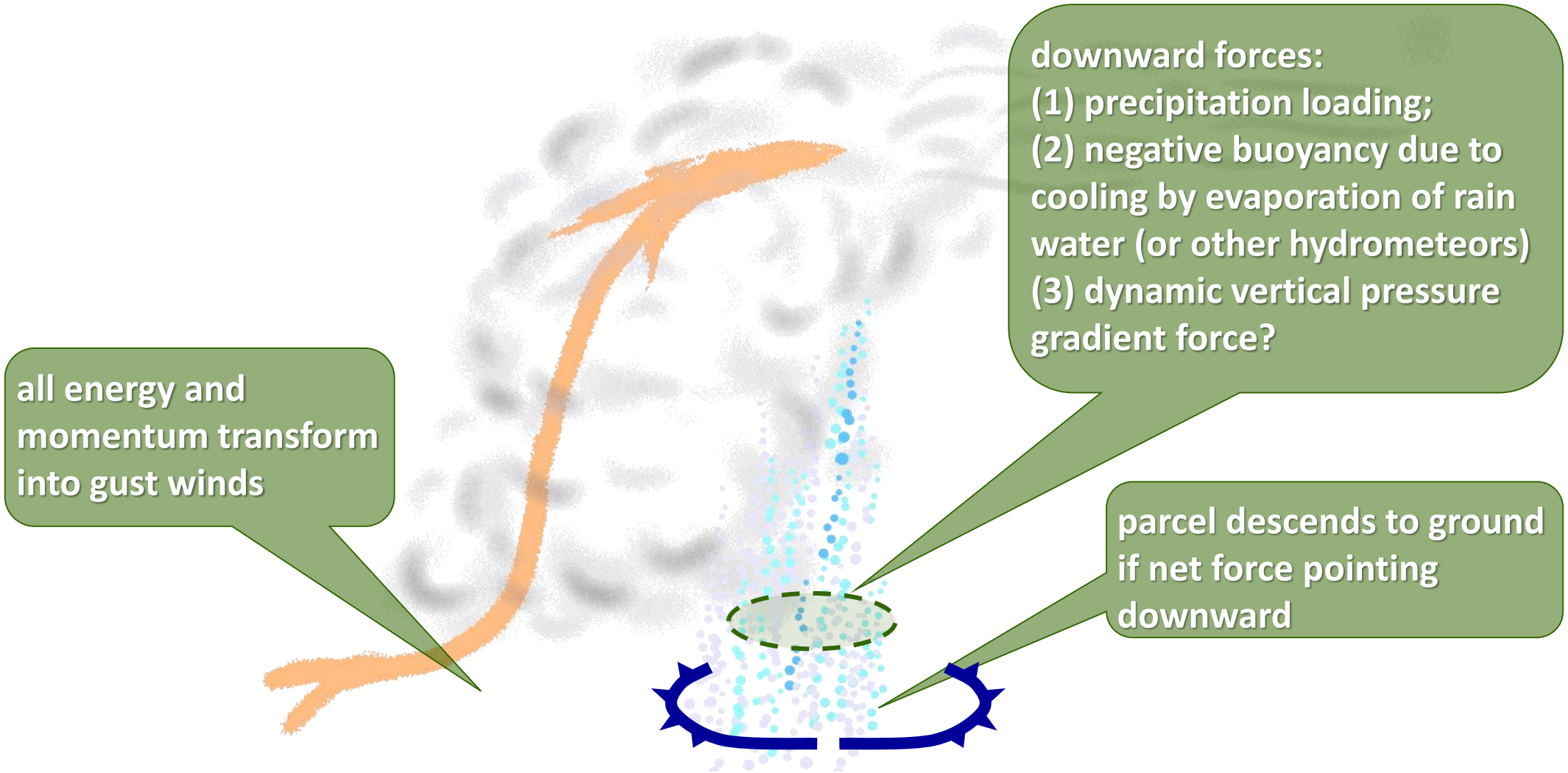
$$v_s^2 = U_{\text{BUOY}} + v_H^2 + U_{\text{LOAD}}$$

buoyancy | initial mom. | precip. loading

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

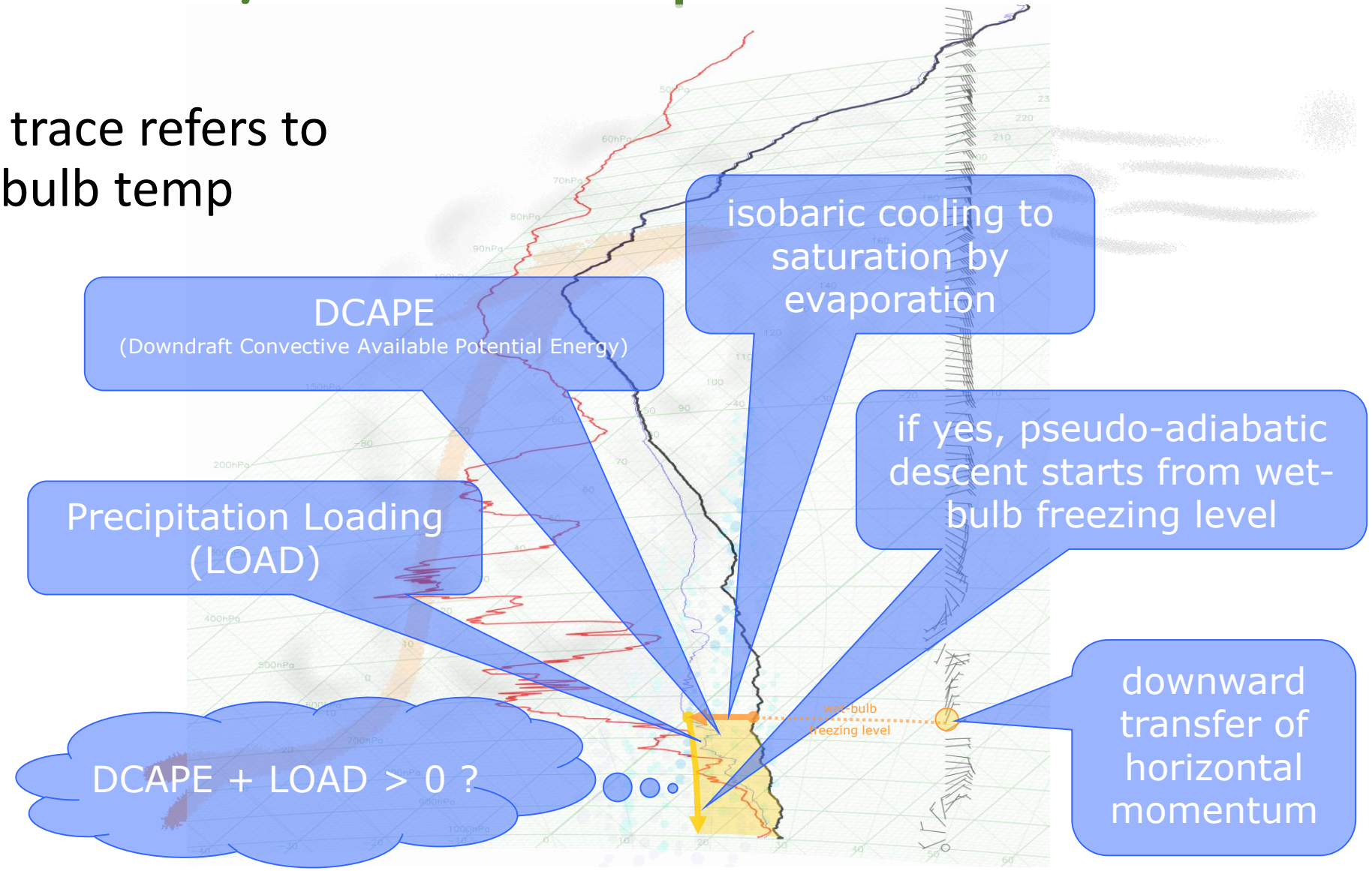
$$U_{\text{LOAD}} = -2\int_0^H L\,dz = 2g\int_0^H r_t\,dz = 20.3 \times \text{VIL}$$

Downburst/Gust Conceptual Model

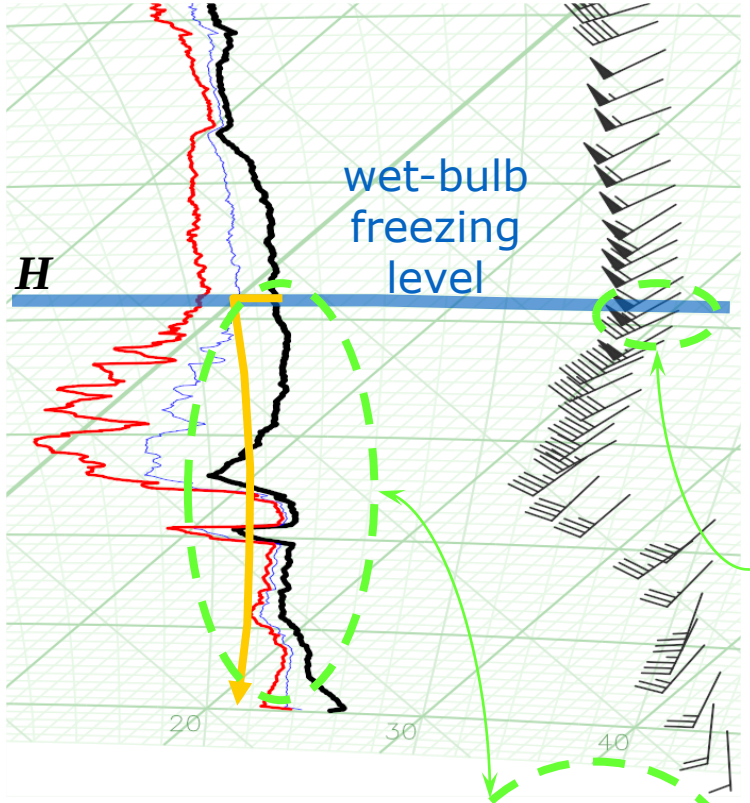


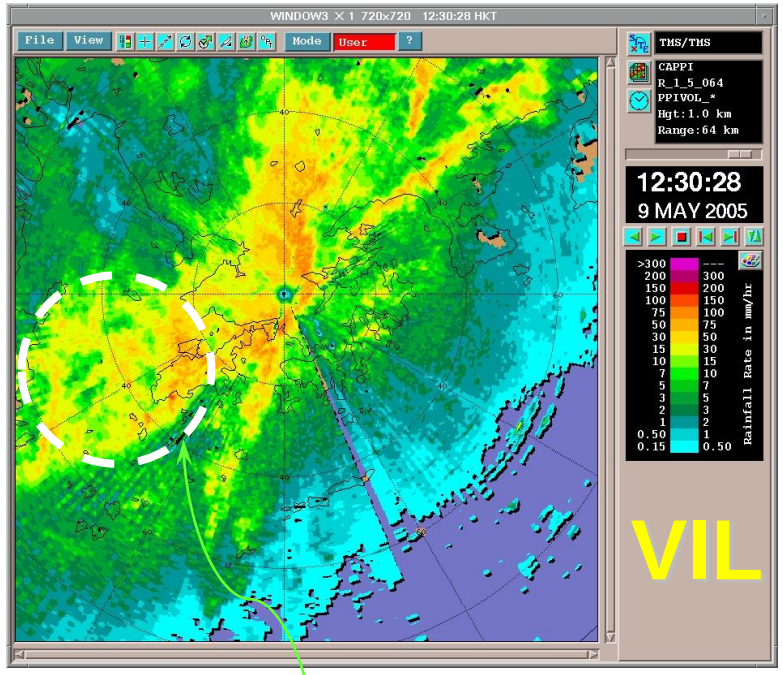
Downburst/Gust Conceptual Model

- Blue trace refers to wet-bulb temp



Downburst/Gust Nowcast Algorithm

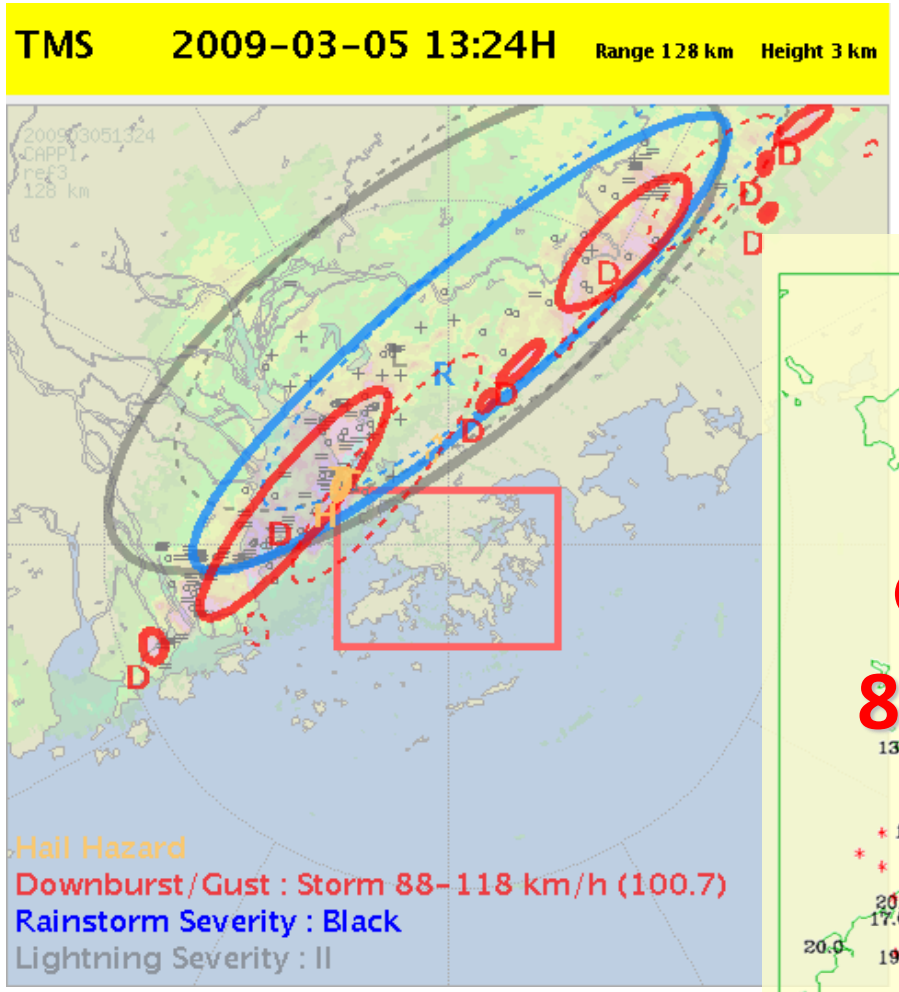




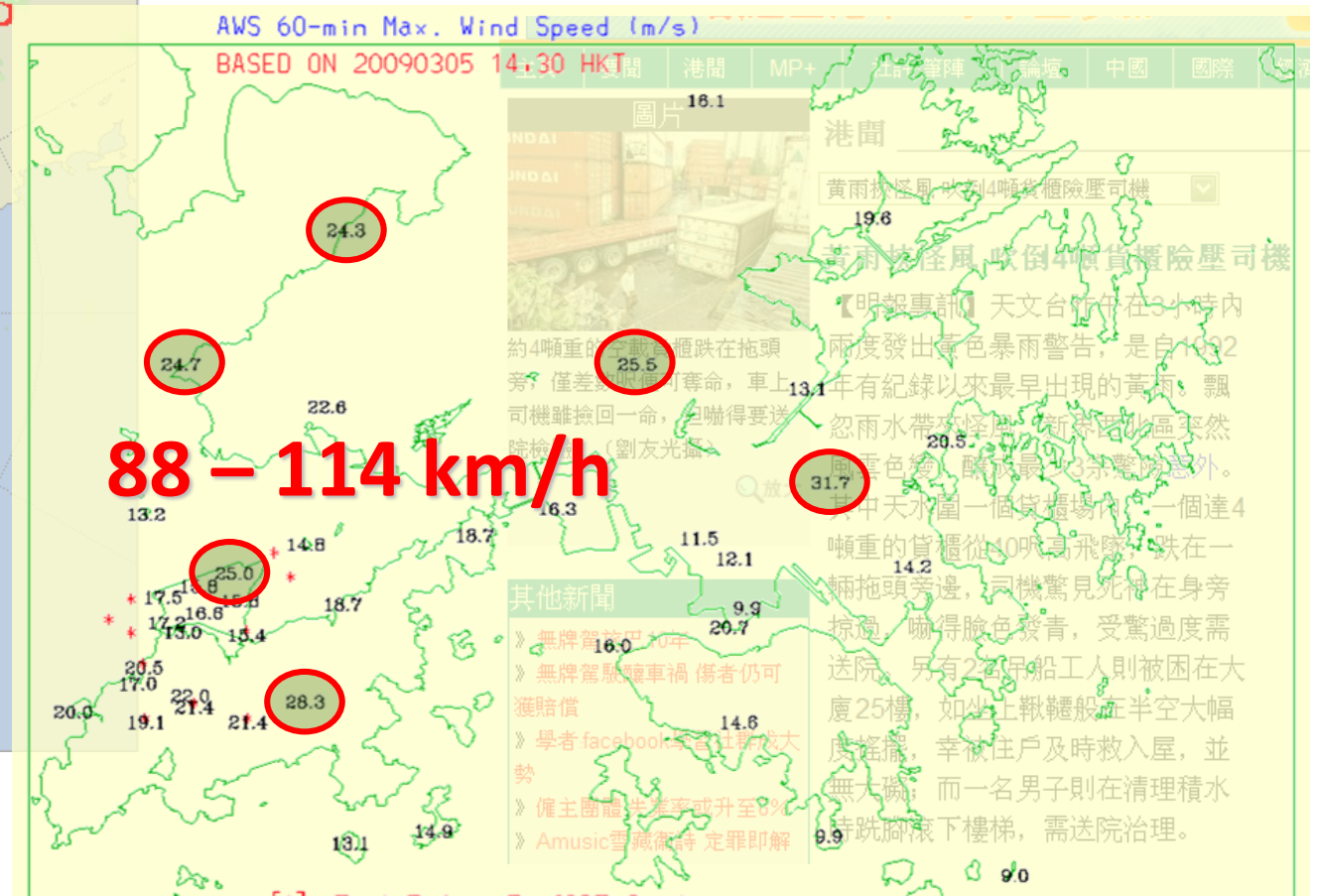
$$w_o^2 = 2g\int_0^H \frac{\theta'_v}{\theta_{vo}}dz + w^2{}_H + 2g\int_0^H Ldz$$

buoyancy | hori. mom. | precip. loading

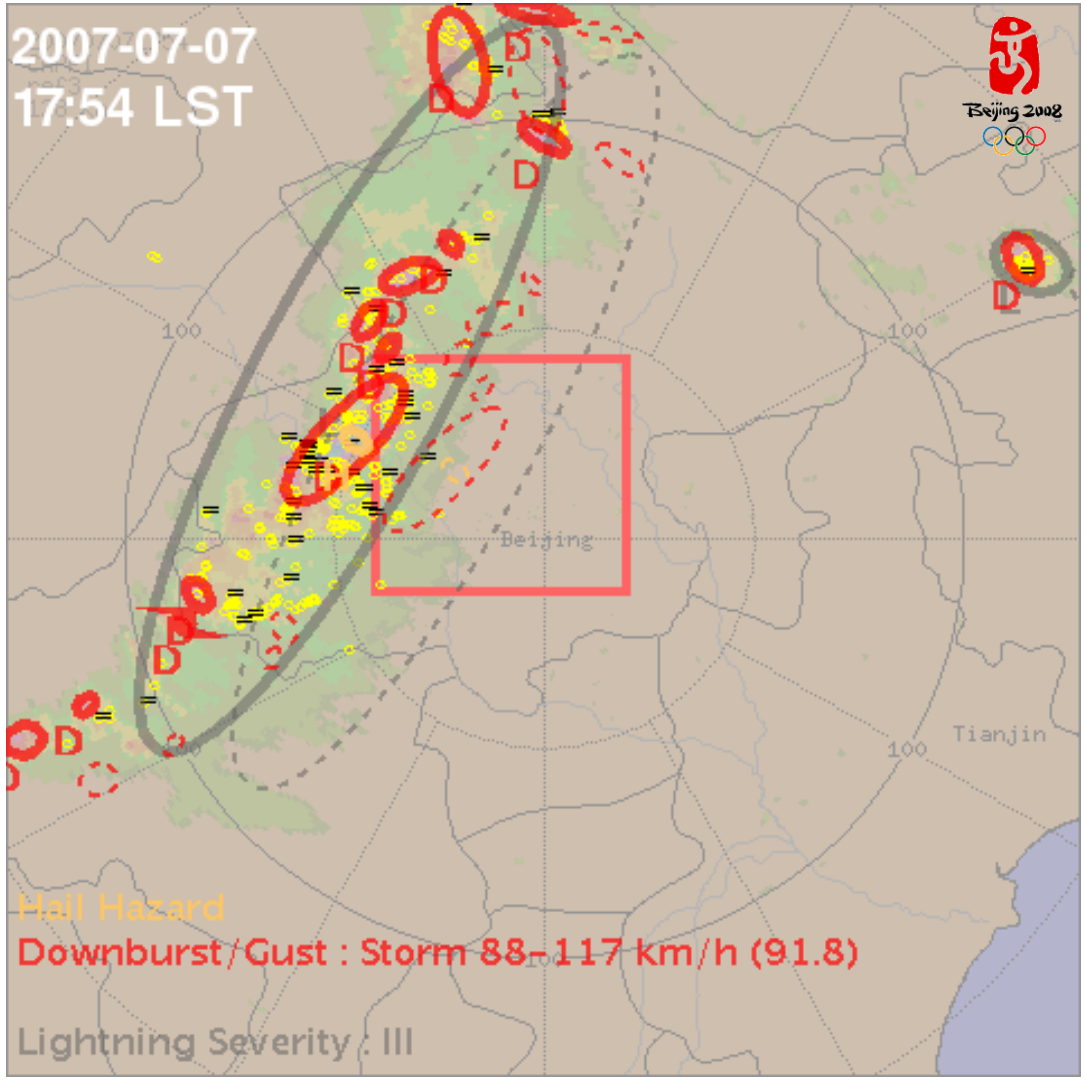
Squall Nowcast – Hong Kong



- squall line of 5 March 2009



Squall Nowcast for Beijing



- damaging winds on 2007-07-07, ~ 7 pm
  - SWIRLS (5:54-7:12 pm) :
    - *Gale F9 (82.2 km/h) to Storm F10 (91.8 km/h)*
  - AWS - WSX (6:30-6:35 pm) :
    - *Gale F9 (78.1 km)*


Beijing Daily Messenger 北京娱乐信报 2007-07-08

吊车没"站稳"砸坏酒楼屋顶

所幸未造成人员伤亡 车队负责人称吊车是大风刮倒的

雷阵雨突袭 气象台两发预警

Some Tips on Usage

- Lightning nowcast
  - based primarily on radar observations and warns about C-G lightning only
  - also checks for actual I-C lightning signals but may be too late due to latency of Beijing lightning data (updated hourly)
  - assumes dominance of -ve strokes in C-G lightning
- Downburst / Wind Gust
  - depending on the actual propagation of the gust fronts, actual gusty areas may be wider or further downstream than those indicated by the D-cells
  - tends to over-warn due to the current data set being derived solely from gusty cases
  - mainly applicable to pulse-type thunderstorms

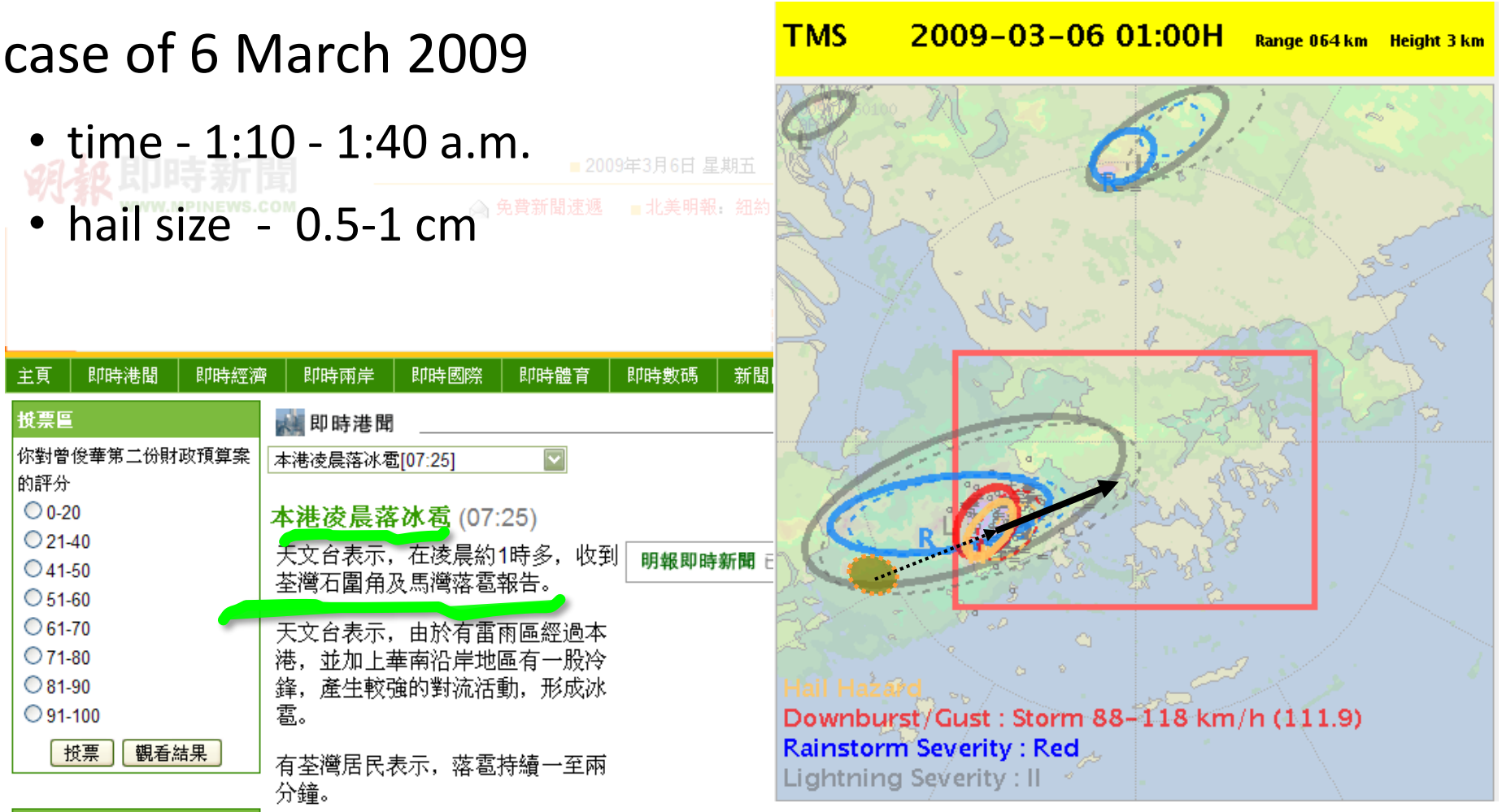
Nowcast of Hail

Hail

- Hail hazard is identified where:
  - 60 dBZ echo can be located above 3 km altitude (60 dBZ Echo TOP radar product); AND
  - up to 2 km altitude, less than 5 mm vertical integrated liquid can be found (2 km VIL radar product)
- Then use ellipses to group the hail hazard area

Hail Nowcast - Hong Kong

- case of 6 March 2009
  - time - 1:10 - 1:40 a.m.
  - hail size - 0.5-1 cm



SWIRLS' HAIL FORECASTS

Reported

Year	Date	Time	Areas of Incidence	Size of Hailstones	Other Remarks
2009	6-三月	0110 H - 0120 H	Tung Chung	diameter: 0.5 - 1 cm soy bean sized	Thunderstorm with heavy rain.
		0120 H	Ma Wan		Hail last for 1 to 2 minutes. Thunderstorm with heavy rain.
		0140 H - 0150 H	Tsing Yi	diameter: 0.5 - 1 cm	Heavy rain
		0130 H - 0140 H	Tsuen Wan	soy bean sized	Thunderstorm with heavy rain.
2013	19-Mar	shorthly before 1800 H	Sheung Sze Wan Clearwater Bay (email)	About 20 seconds with stones the size of peas	Thunderstorm with heavy rain. Amber in force Trough of low pressure is bringing rain and thunderstorms to the coastal areas of Guangdong. Locally, rain and thunderstorms in the afternoon and evening brought more than 30 millimetres of rainfall to Hong Kong Island and Lantau Island)
		Around 1730 H	The peak, near Black's Link (newspaper)	About 30 seconds,soy bean sized	
2014	30-Mar	Around 2040 H	Tuen Mun, Yuen Long, Tsuen Wan, Tsing Yi, Kowloon Tong, Kwai Chung	marble sized, diameter:1-3 cm	Thunderstorm with heavy rain. Black in force. Trough of low pressure. Hail last for 10 min

SWIRLS Hail Forecast (since 2011)

2009 (Partial): 3/5, **3/6 (01:18)**

2010 (Partial): 5/7 (x2), 9/8, 9/10

2011 (Full Year): 4/17, 7/28

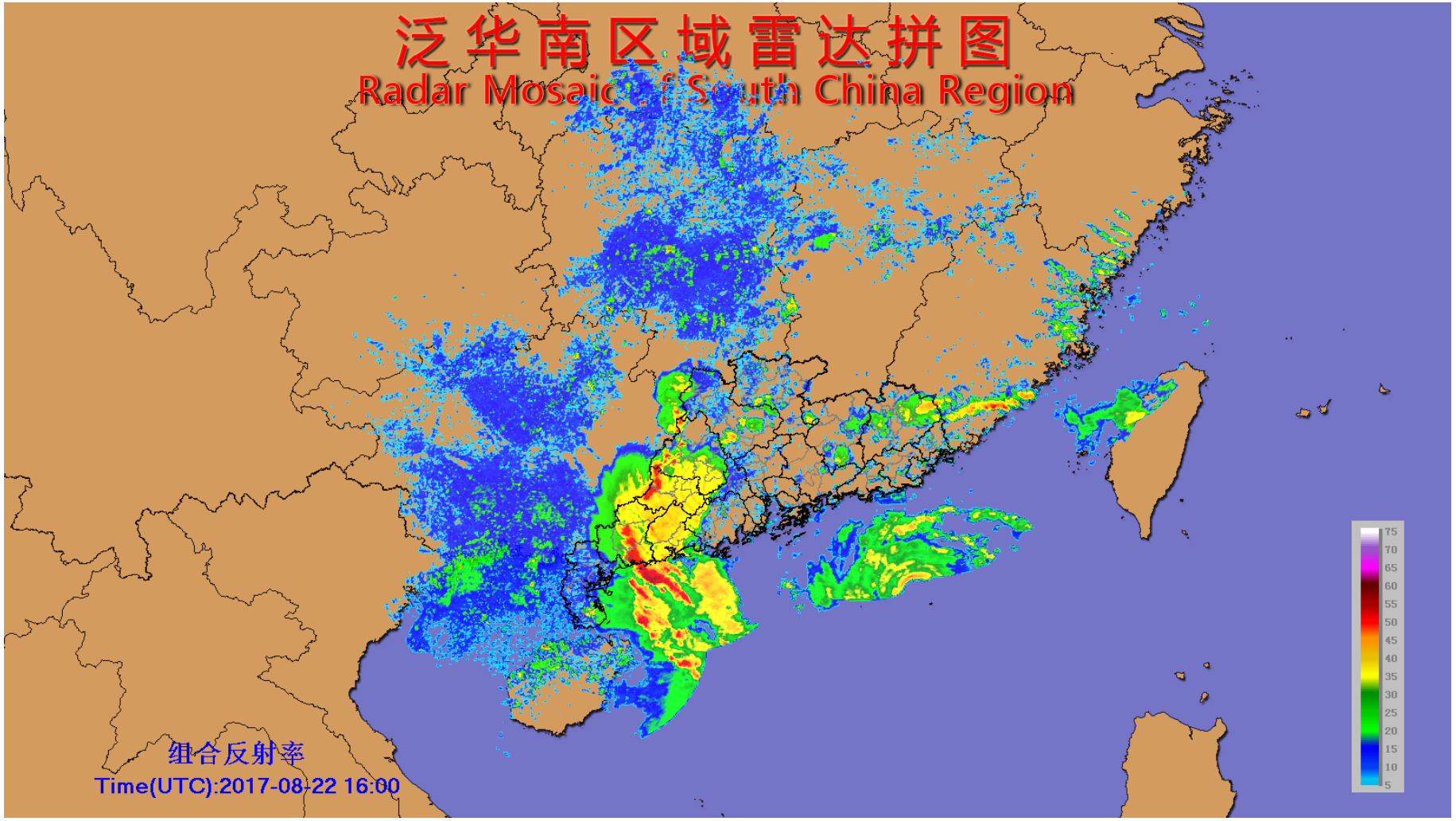
2012 (Full Year): 4/13, 4/16, 5/4 (x2), 5/10, 7/21, 7/31,

2013 (Full Year): **3/19 (14:24)**, 3/28

2014 (Full Year): **3/30 (18:30** & 2318**)**, 3/31, **4/2 (05:00 & 21:30)**, 4/3

Satellite Nowcast Application

Why Satellite Retrieved Reflectivity?



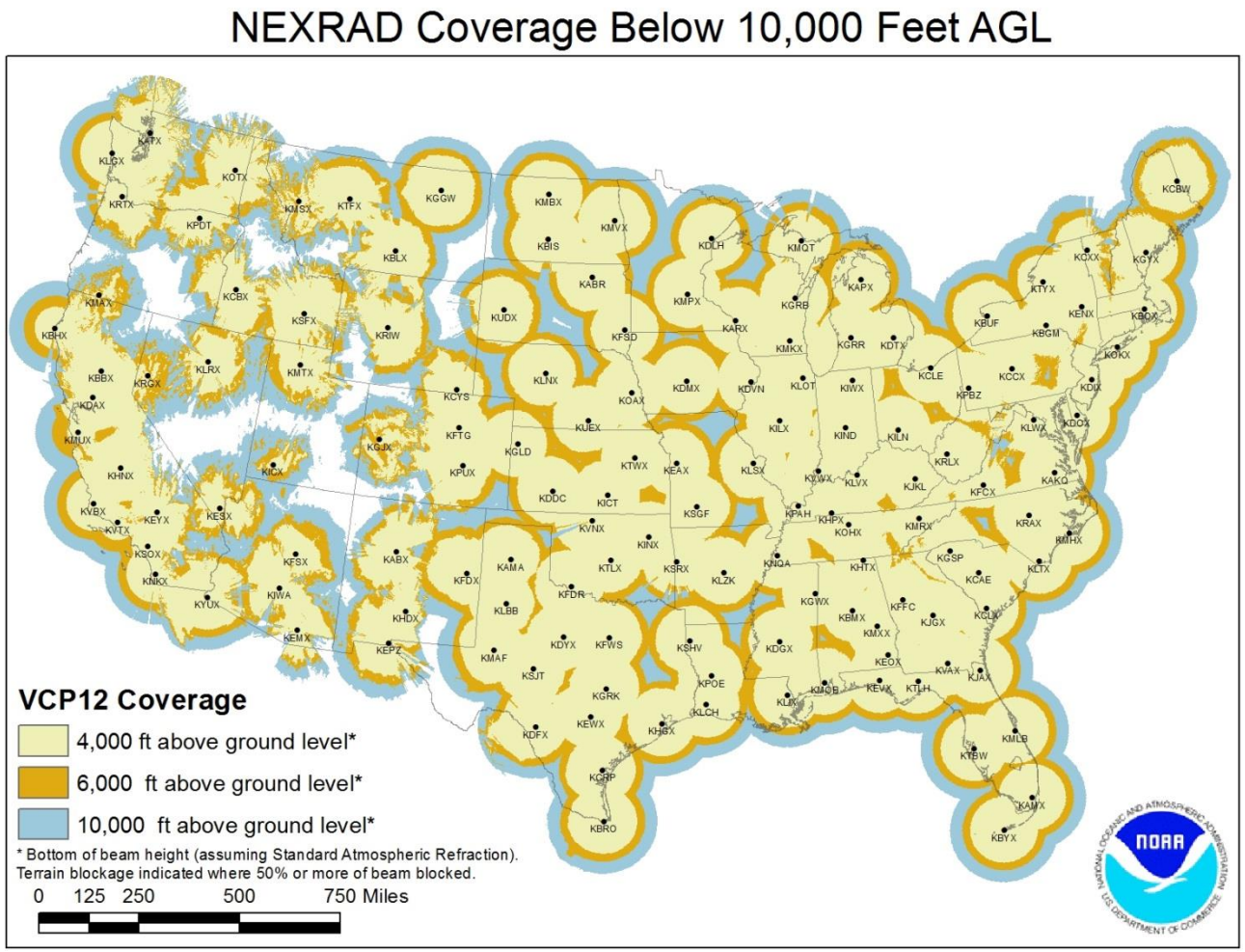
12 hours before Super Typhoon Hato (1713) landed over Zhuhai, near Macao

Radars are vulnerable in Tropical Cyclones

Puerto Rico weather radar
destroyed by Hurricane Maria

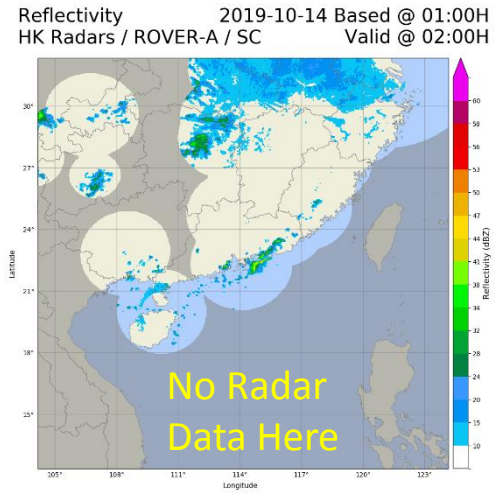
Wufenshan weather radar
destroyed by Super Typhoon
Soudelor (1513)
Credit: Ettoday.net

Coverage of Radar Network

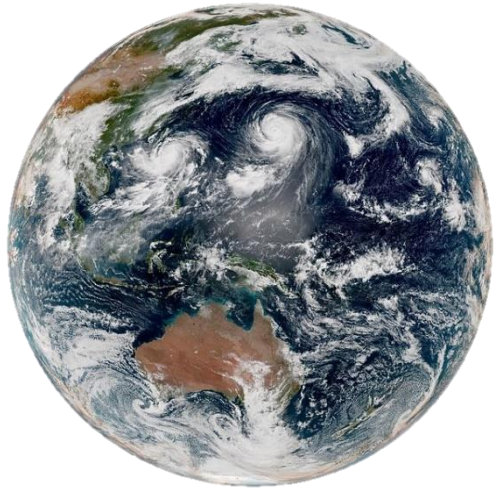


Source: https://www.roc.noaa.gov/WSR88D/Maps.aspx

Simulate Radar Observations from Satellite Data using Neural Network

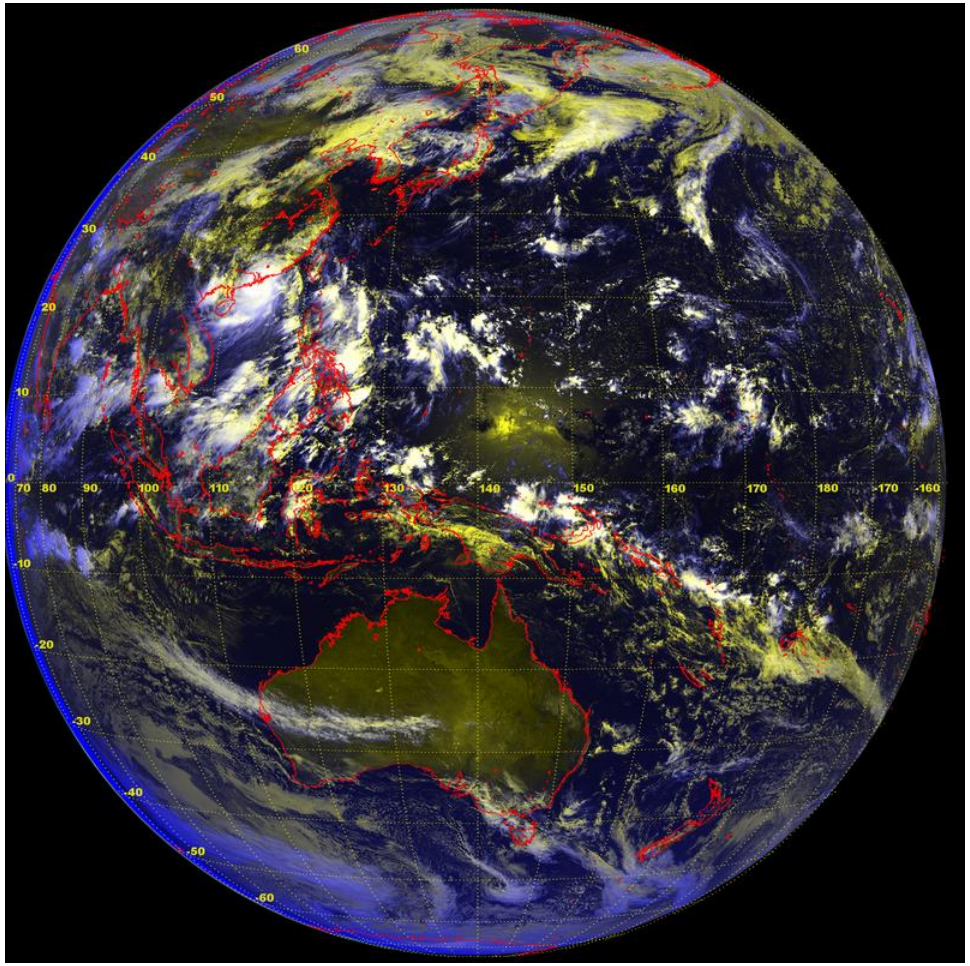


Radars can detect Rain,
but have Limited Coverage

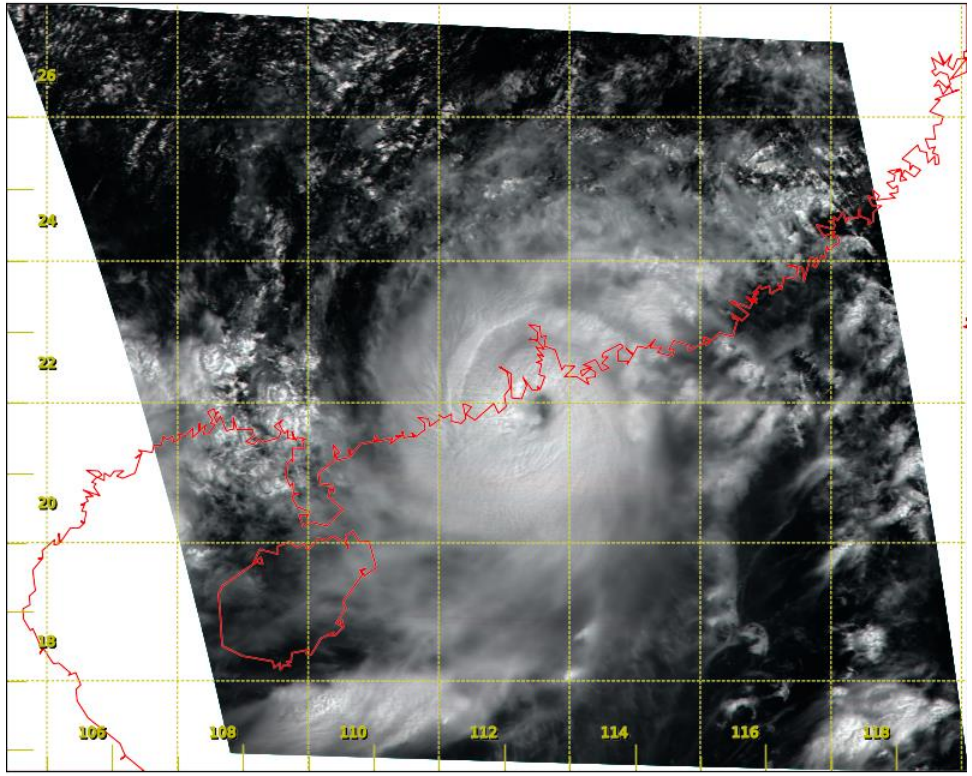


Satellites have Wide Coverage, but
can only see Cloud, Not Rain

Third Generation Satellite: Himawari-8



Full disc: once every 10 mins



Rapid-scan: once every 2.5 mins

Spectral Information from Himawari-8

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

Satellite vs Radar

	Radar (e.g. NEXRAD)	Satellite (e.g. Himawari-8)
Temporal Resolution	4/5/6/10 minutes	10 minutes (full dsic) 2.5 minutes (target & Japan)
Spatial Resolution	250 m (range increment) 1/0.5º (azimuth increment)	0.5 km (B3/Red) 1.0 km (B1, B2, B4) 2.0 km (others)
Range	256 km (Effectively Useful) 512 km (Limited Use)	Almost half the Globe
2D / 3D?	Basically 3D (except the cone above the highest beam)	Mostly 2D (top down)
Correlation with precipitation	Better	Not as good

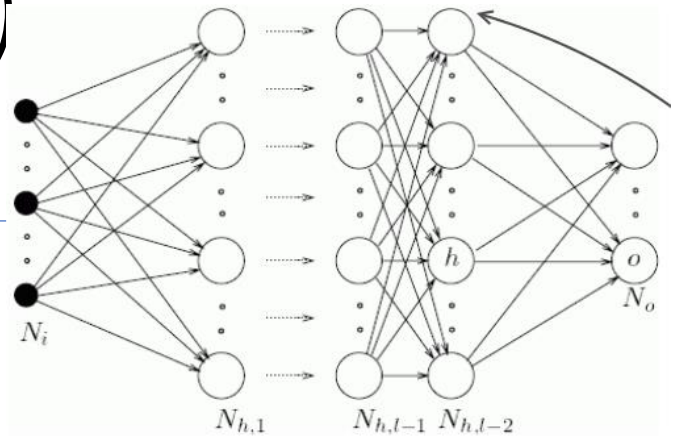
What If?

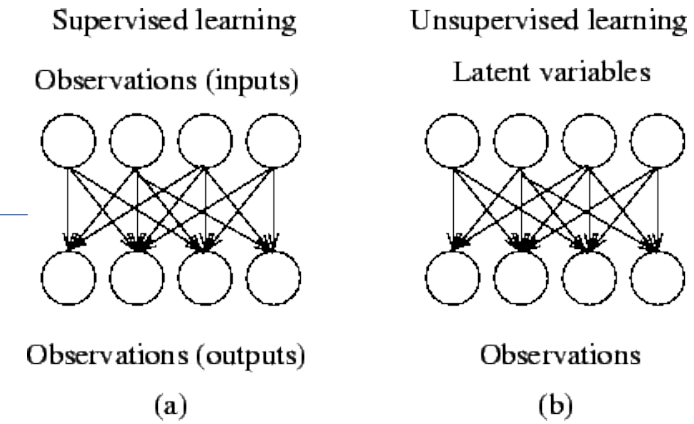
- We have a field with
  - Data like Radars
  - Coverage like Satellites

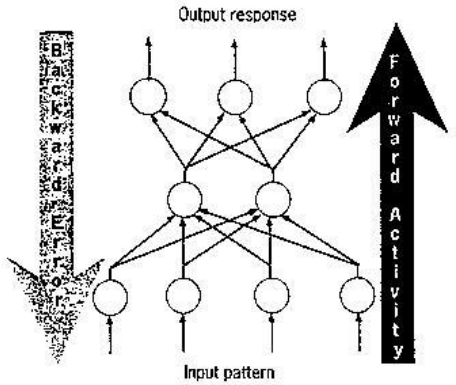
Multi-layer perceptron artificial neural network (MLPANN)

- Features of MLPANN implemented in HKO:

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



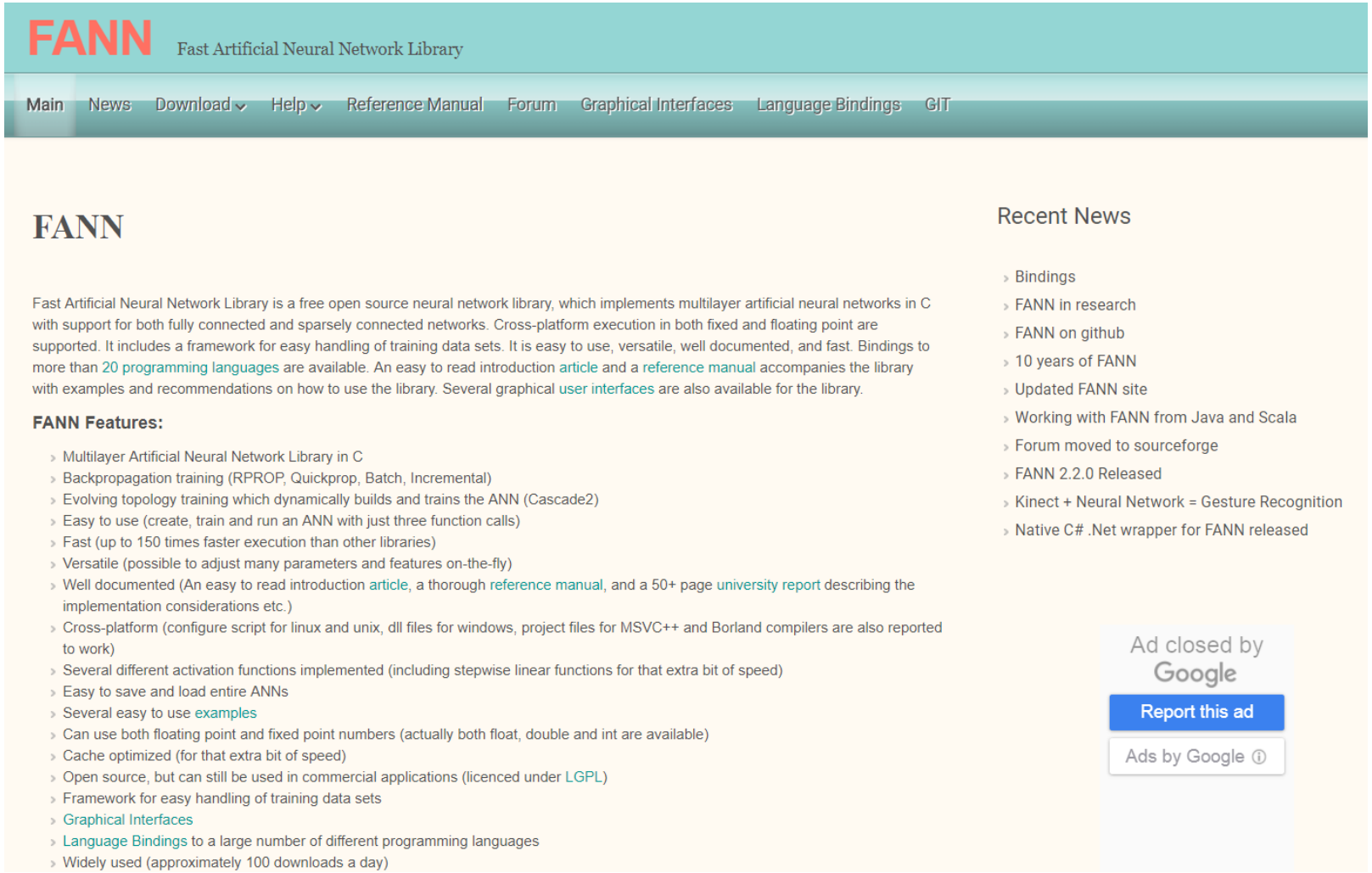




A backpropagation network trains with a two-step procedure. The activity from the input pattern flows forward through the network, and the error signal flows backward to adjust the weights.

Reference:
http://www.turingfinance.com/misconceptions-about-neural-networks/

Use of
fast artificial neural network (fann) library



FANN Fast Artificial Neural Network Library

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FANN

Fast Artificial Neural Network Library is a free open source neural network library, which implements multilayer artificial neural networks in C with support for both fully connected and sparsely connected networks. Cross-platform execution in both fixed and floating point are supported. It includes a framework for easy handling of training data sets. It is easy to use, versatile, well documented, and fast. Bindings to more than 20 programming languages are available. An easy to read introduction article and a reference manual accompanies the library with examples and recommendations on how to use the library. Several graphical user interfaces are also available for the library.

FANN Features:

- Multilayer Artificial Neural Network Library in C
- Backpropagation training (RPROP, Quickprop, Batch, Incremental)
- Evolving topology training which dynamically builds and trains the ANN (Cascade2)
- Easy to use (create, train and run an ANN with just three function calls)
- Fast (up to 150 times faster execution than other libraries)
- Versatile (possible to adjust many parameters and features on-the-fly)
- Well documented (An easy to read introduction article, a thorough reference manual, and a 50+ page university report describing the implementation considerations etc.)
- Cross-platform (configure script for linux and unix, dll files for windows, project files for MSVC++ and Borland compilers are also reported to work)
- Several different activation functions implemented (including stepwise linear functions for that extra bit of speed)
- Easy to save and load entire ANNs
- Several easy to use examples
- Can use both floating point and fixed point numbers (actually both float, double and int are available)
- Cache optimized (for that extra bit of speed)
- Open source, but can still be used in commercial applications (licenced under LGPL)
- Framework for easy handling of training data sets
- Graphical Interfaces
- Language Bindings to a large number of different programming languages
- Widely used (approximately 100 downloads a day)

Recent News

- Bindings
- FANN in research
- FANN on github
- 10 years of FANN
- Updated FANN site
- Working with FANN from Java and Scala
- Forum moved to sourceforge
- FANN 2.2.0 Released
- Kinect + Neural Network = Gesture Recognition
- Native C# .Net wrapper for FANN released

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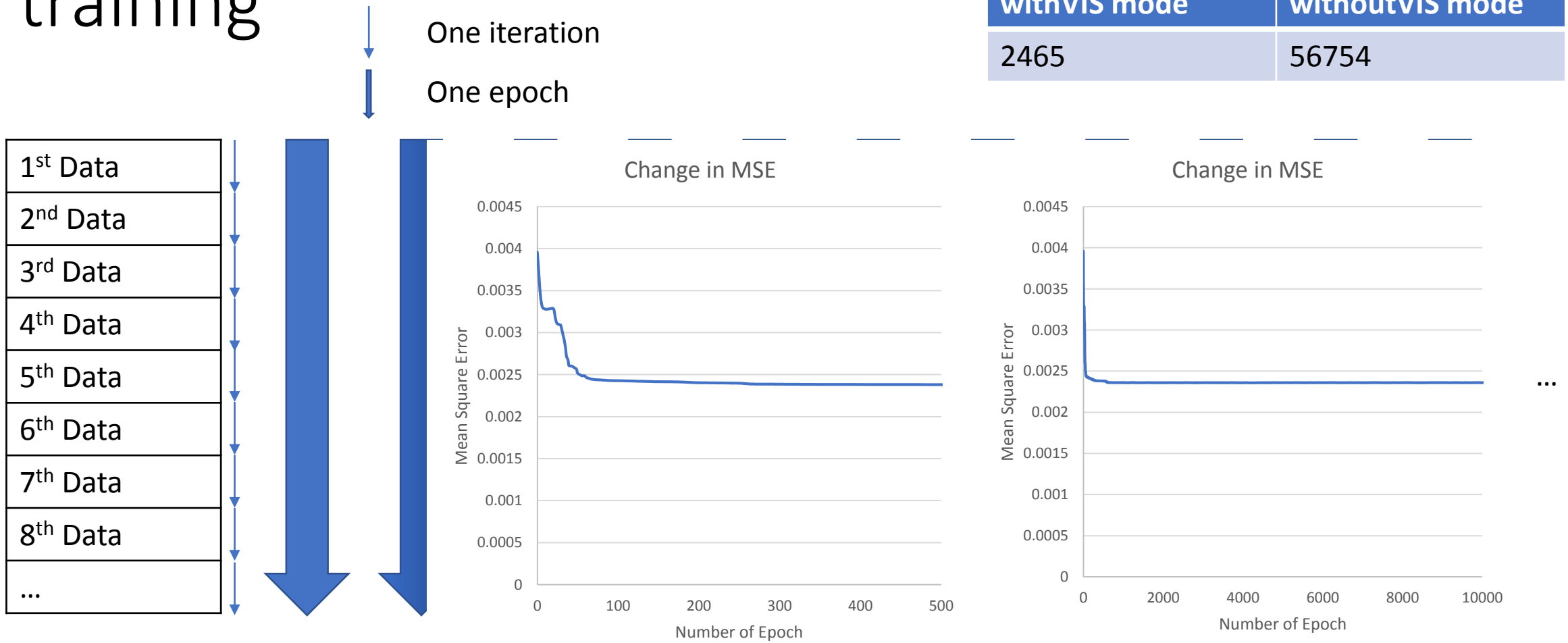
http://leenissen.dk/fann/wp/

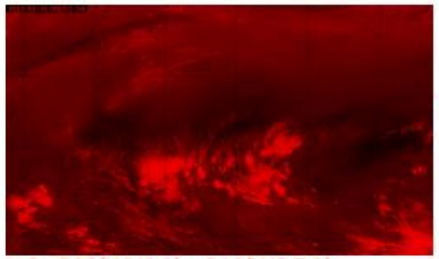
Optimize performance through repeat training

withVIS mode	withoutVIS mode
2465	56754

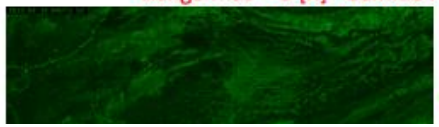


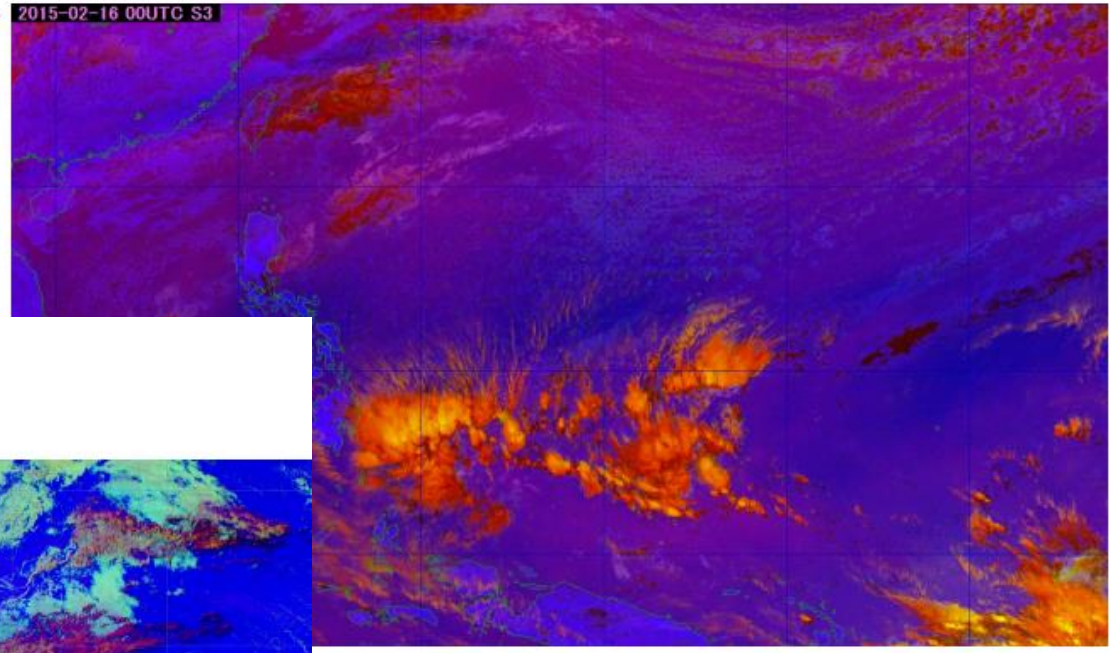
neural network training

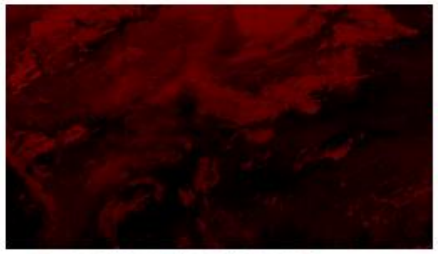
- Training Period:
  - July 2015 - June 2016 (12 months)
- Demarcation for Training & Verification
  - Even Hours for Training
  - Odd Hours for Verification



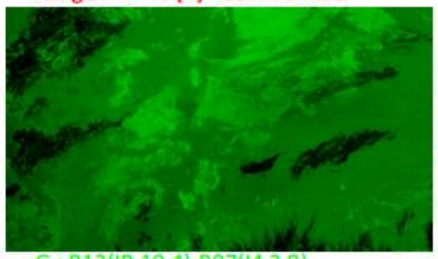
R : B08(WV6.2) – B10(W3 7.3)
Range : -35～5 [K] Gamma : 1.0



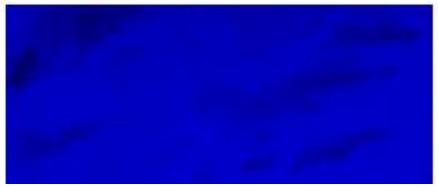


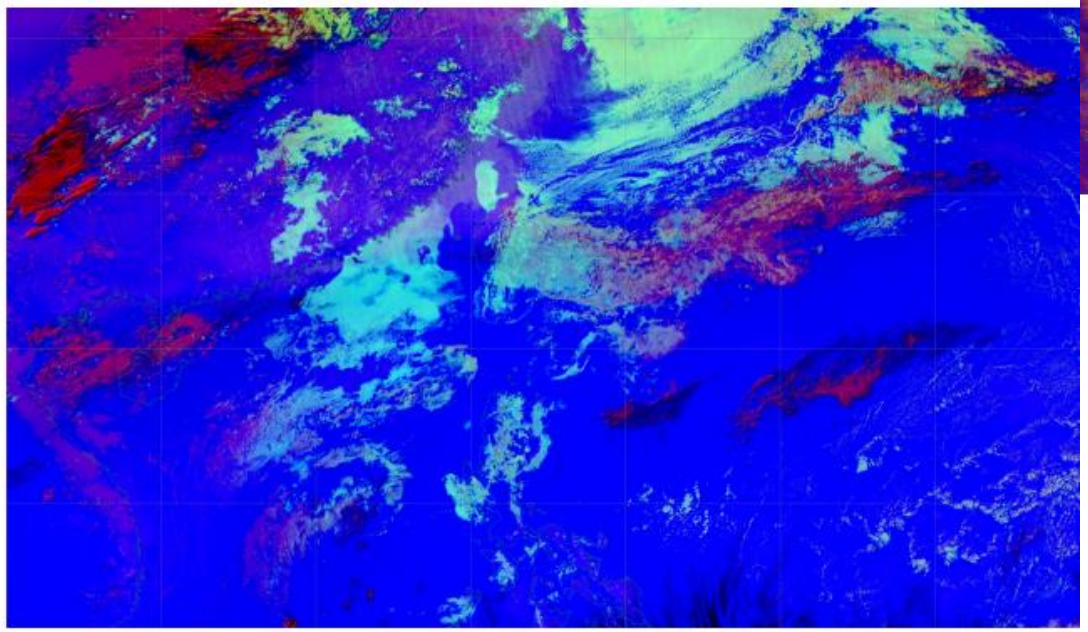


R : B15(I2 12.3)-B13(IR 10.4)
Range : -4～2 [K] Gamma : 1.0



G : B13(IR 10.4)-B07(I4 3.9)
Range : 0～10 [K] Gamma : 1.0

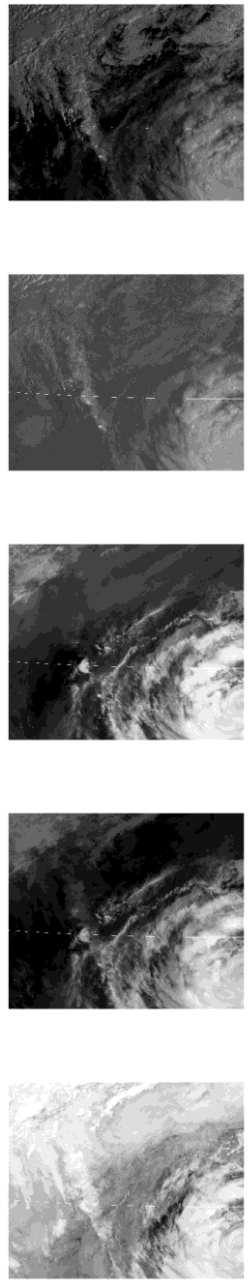




2015-02-16 10UTC

Inputs

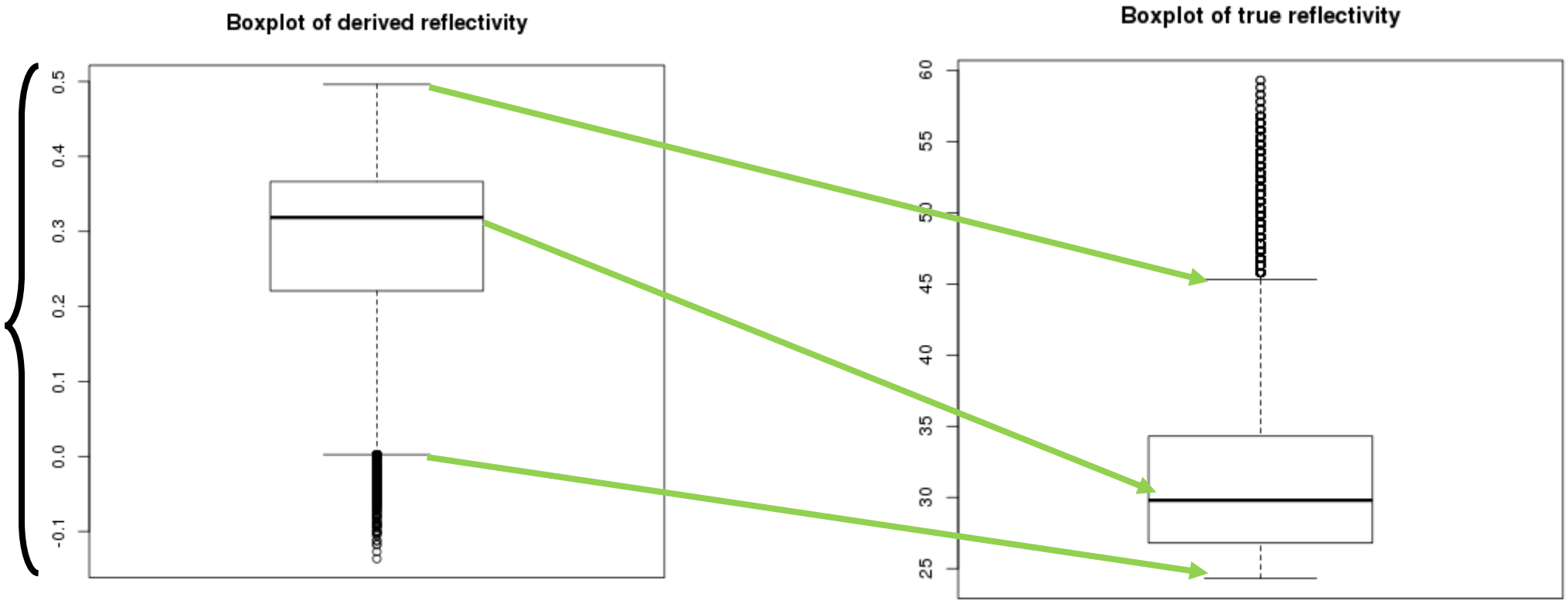
Input	Description
B03 (VIS0.64)	VIS0.64. Reflectivity of B03 depends on optical thickness. Thick cloud are displayed in white.
B05 (NIR1.6) - B04 (N1 0.86)	Difference between NIR1.6 and N1 0.86. B04 has high reflectivity for snow/ice covered area and clouds, sea surface looks dark. Reflection characteristic 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
~~Minimal Brightness Temperature of IR1 in Pixel Rings~~	~~Distinguish Spatial Separation of Target Pixel and Cloud Top~~
~~Brightness Temperature Standard Deviation of IR1 in Pixel Rings~~	~~Local texture, assisting is classifying cloud type~~
~~Average Brightness Temperature of IR1 in Pixel Rings~~	~~Indicate Convective Strength of Surrounding Area~~



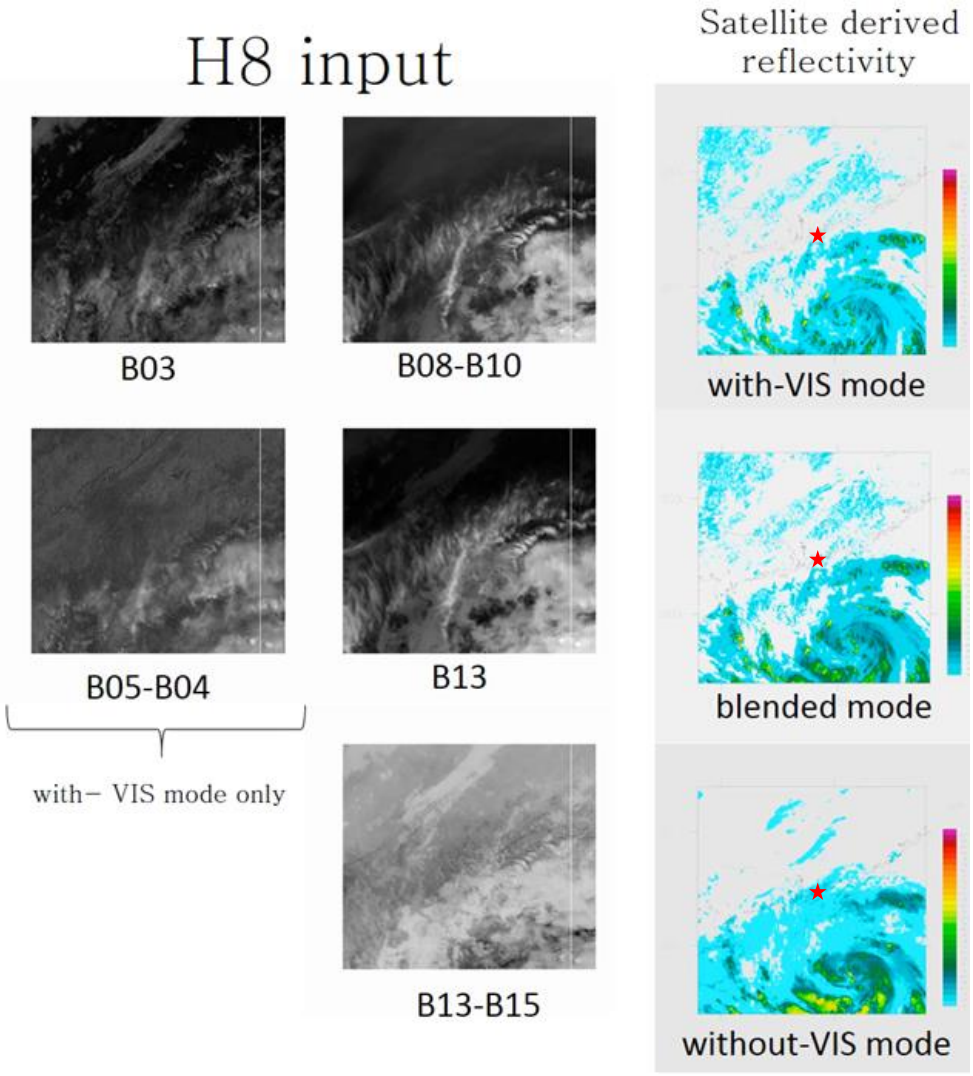
Frequency Matching

Normalized Output of Neural Network

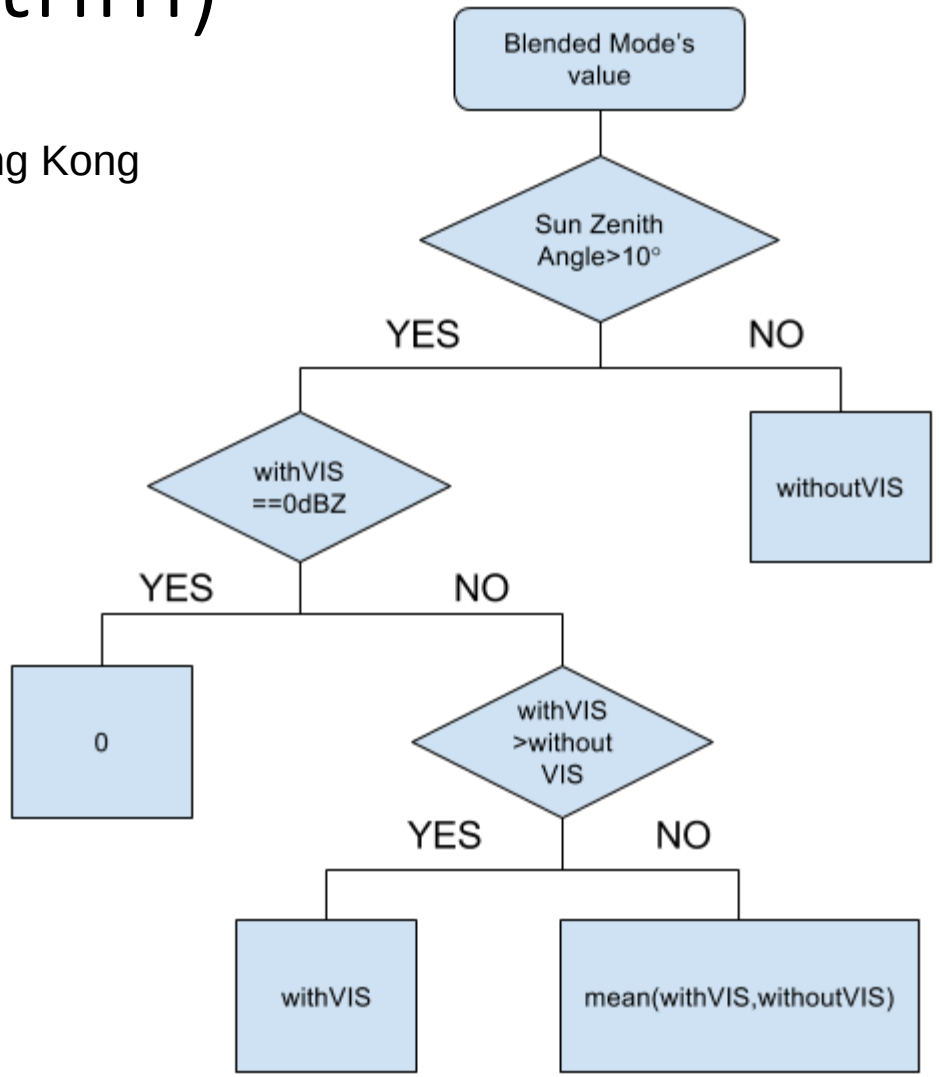
(from -1 to 1)



with-VIS mode, without-VIS mode, blended mode (composite algorithm)



★ Hong Kong

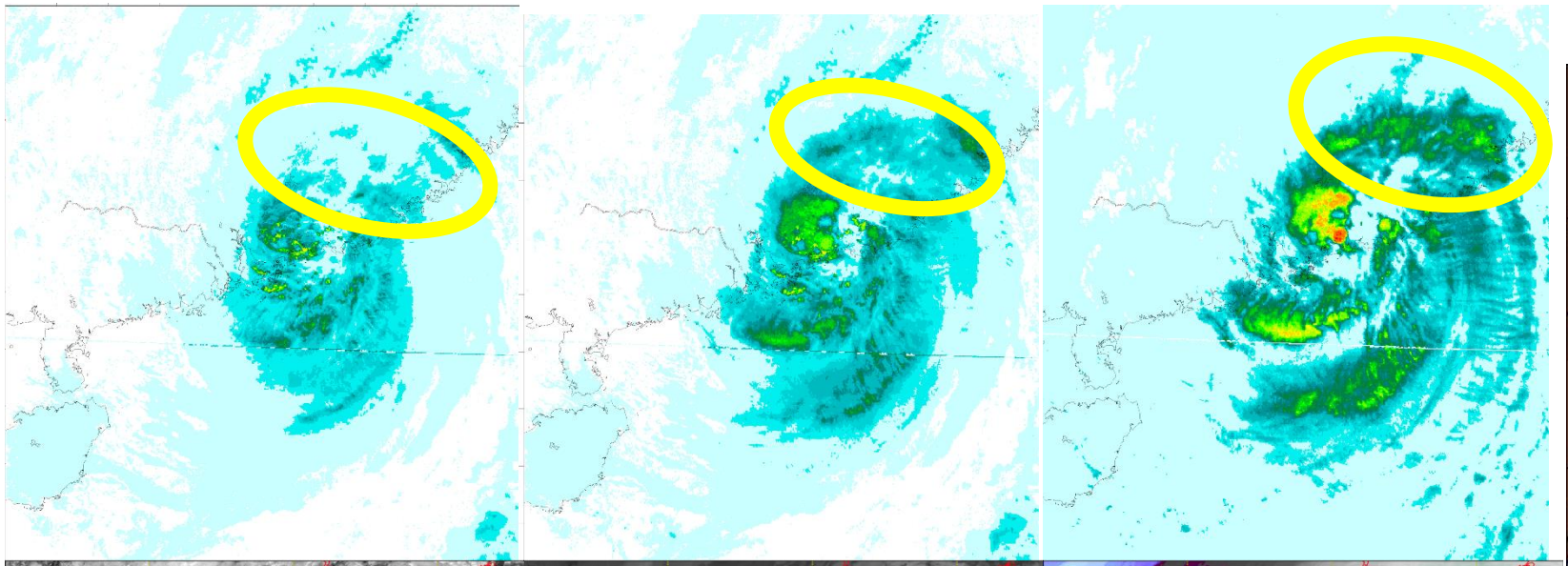


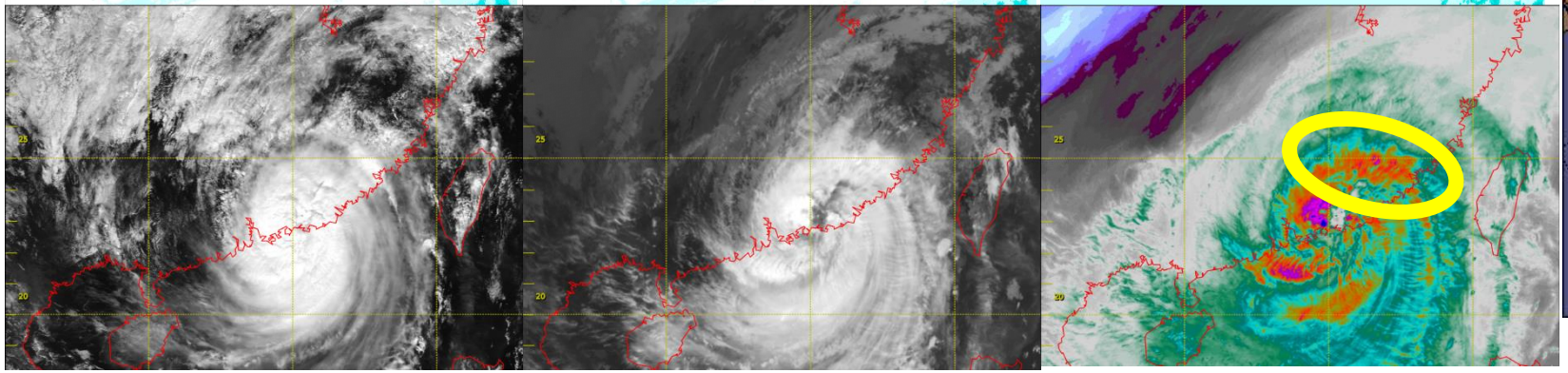
Compare with Available Satellite Product

With-VIS Mode

Blend Mode

Without-VIS Mode



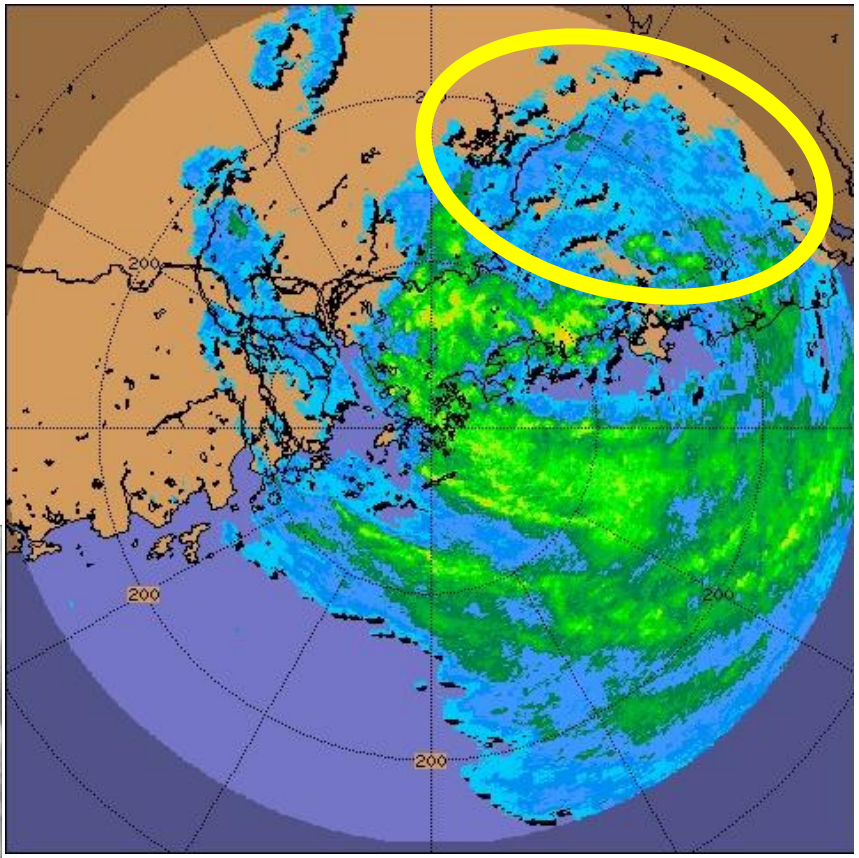


Visible

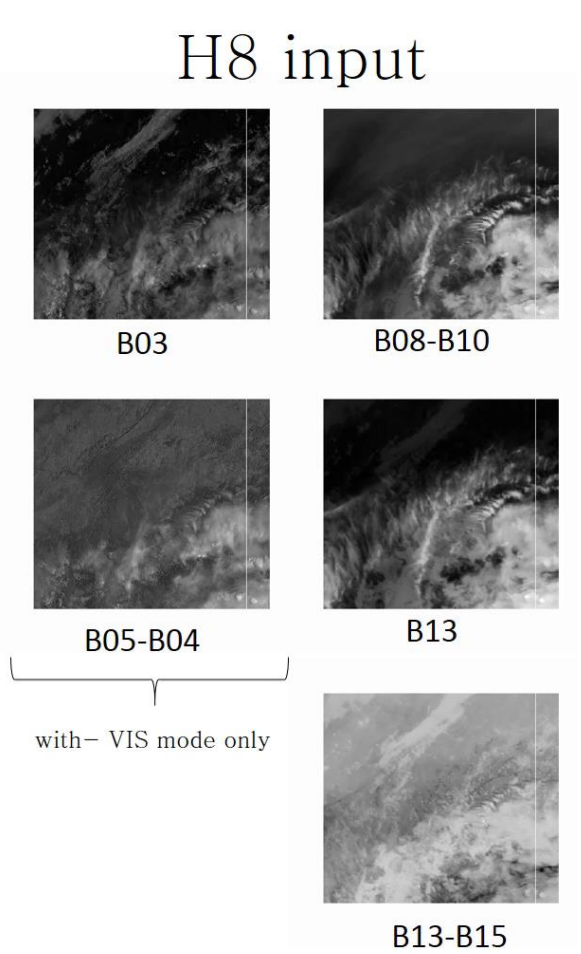
IR1

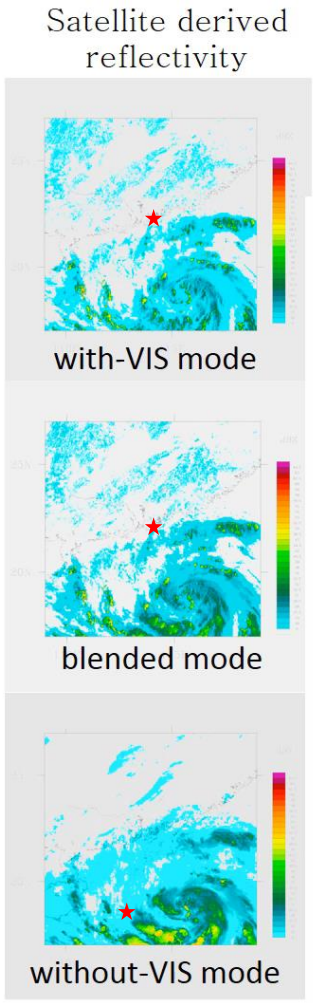
WV

2016 Typhoon Haima
20161021 UTC0400



Demonstration of application- MSQ





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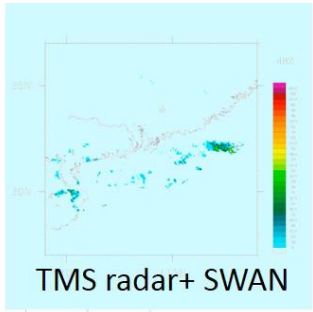
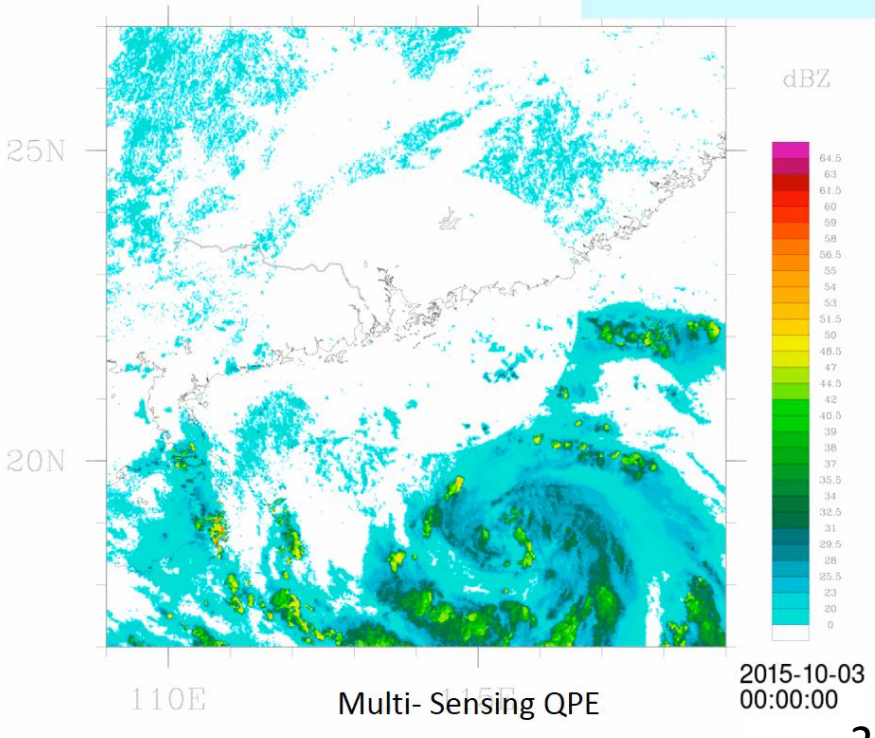
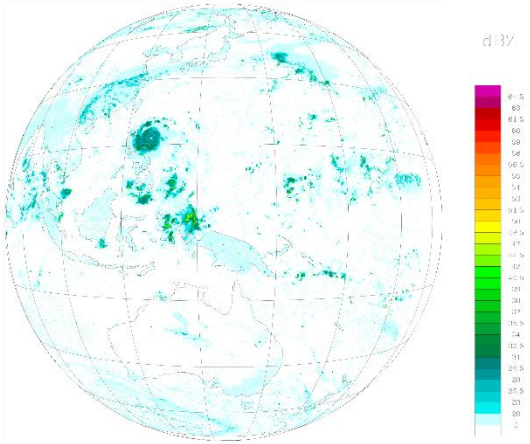




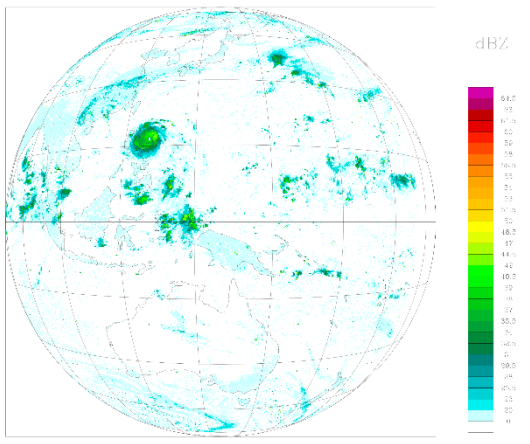
2015 Typhoon Mujigae

Demonstration of application- Reflectivity map in different projection/ scales

20161019_0300_fulldisk_DAY



20161019_0300_fulldisk_BLENDED



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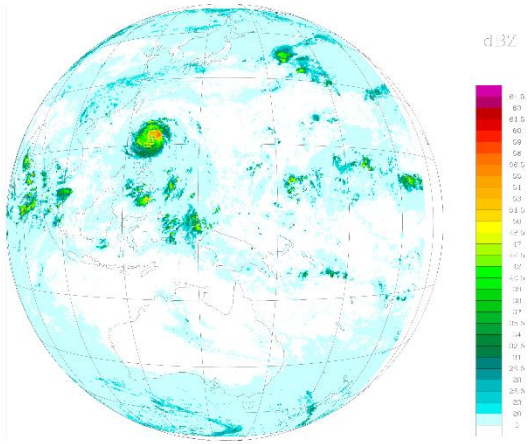

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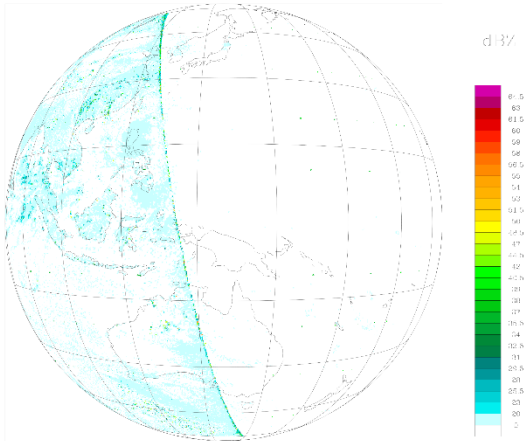

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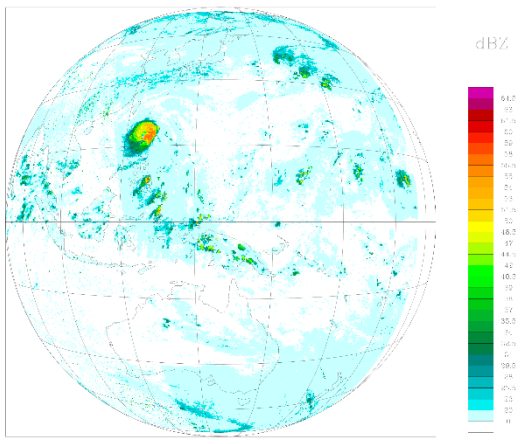

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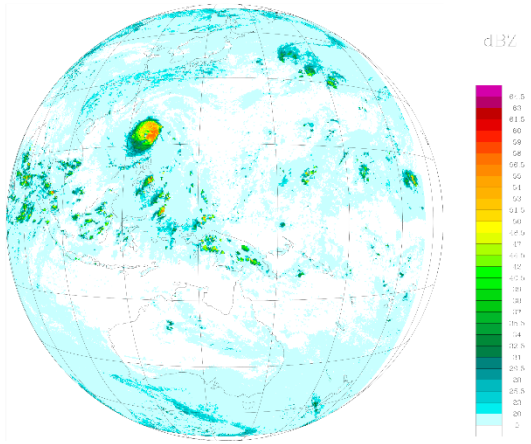
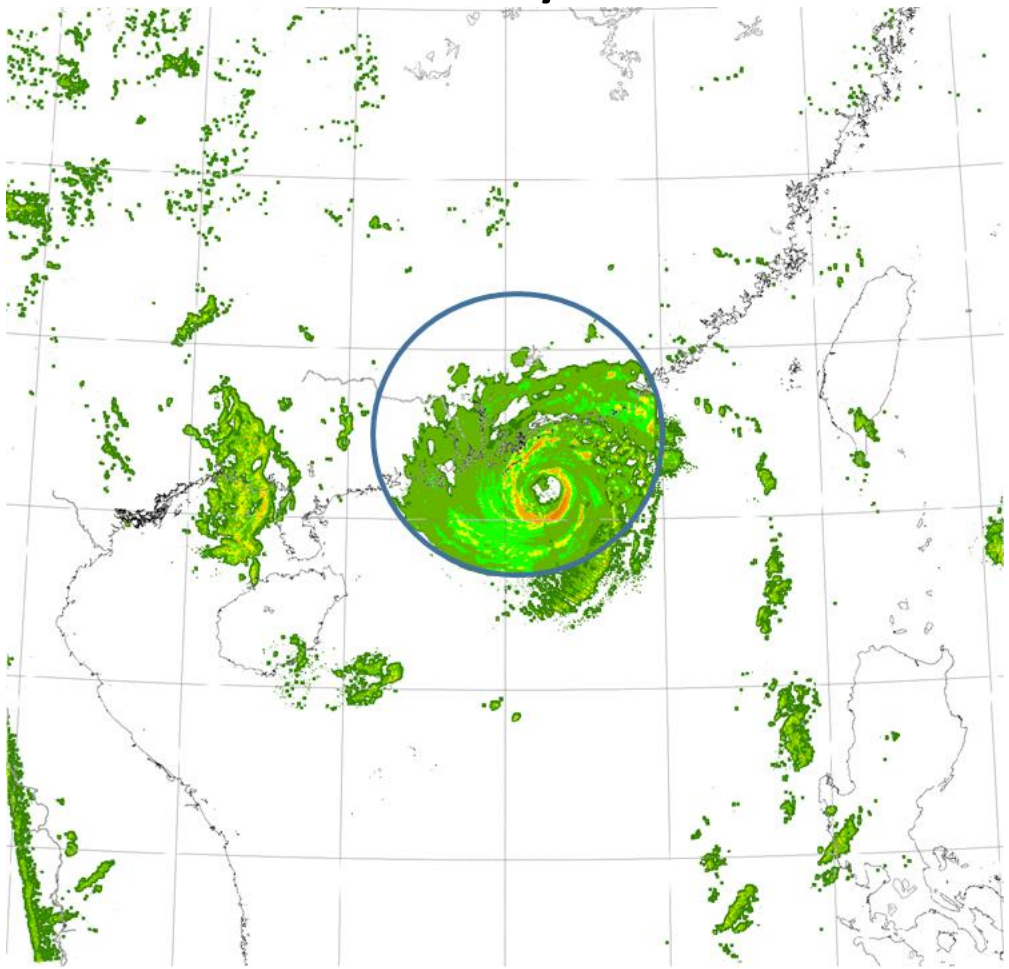
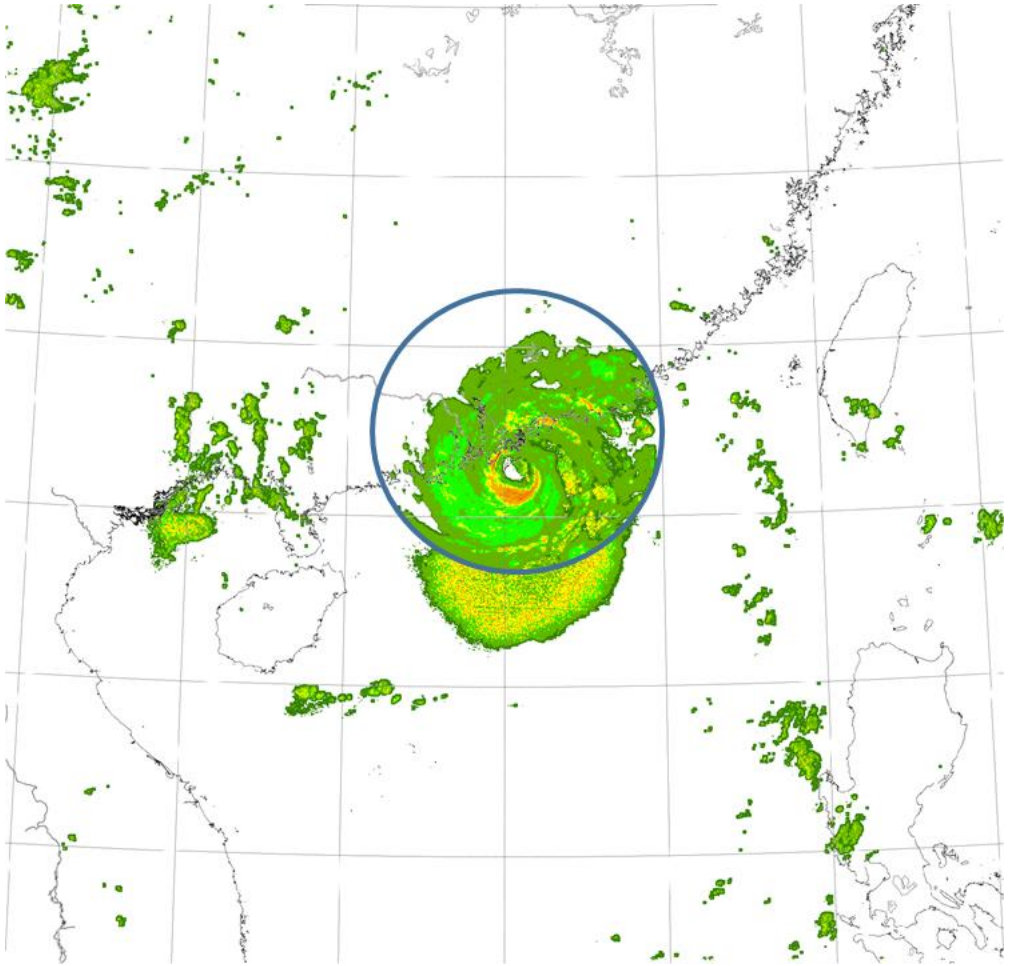


Blending Syntheic Reflectivity with Real Reflectivity

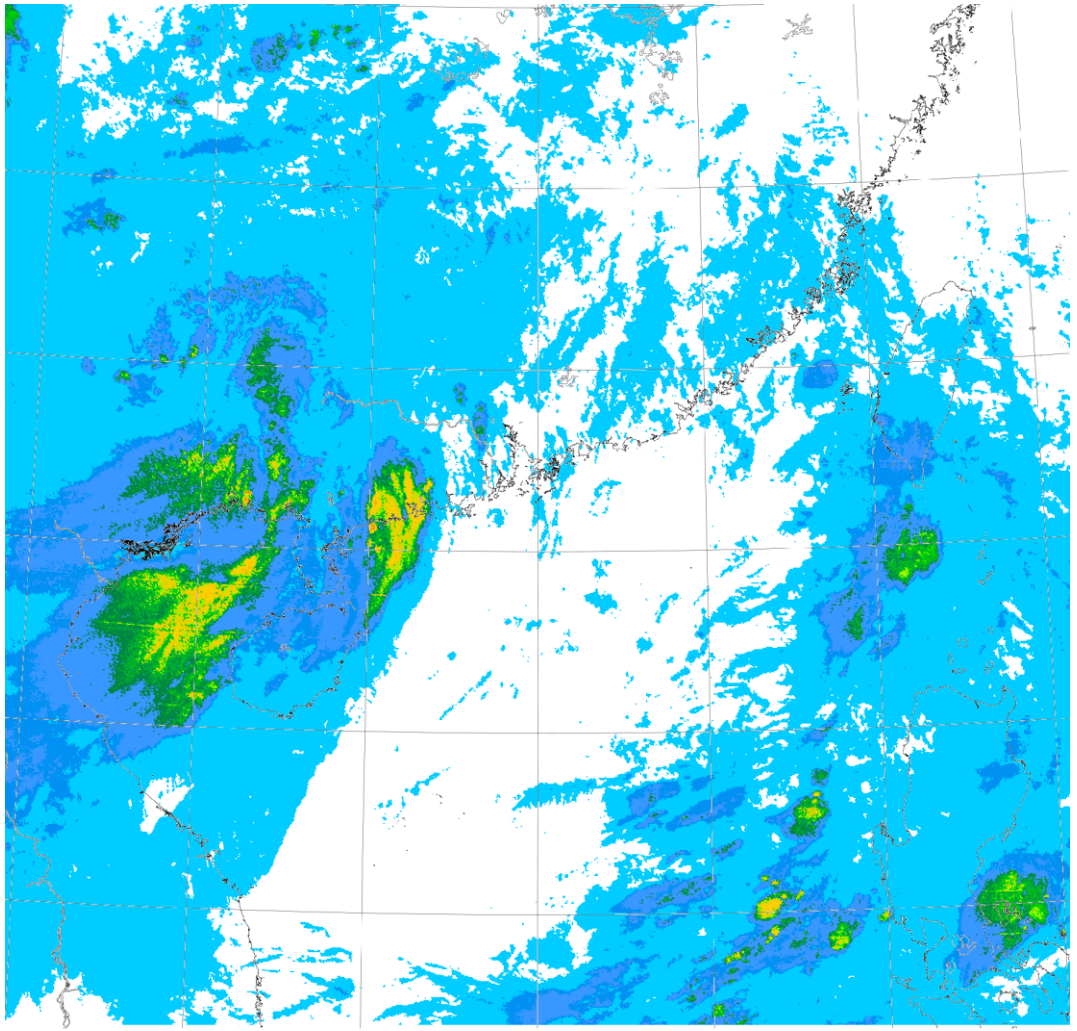


2017/08/23 07:00 HKT



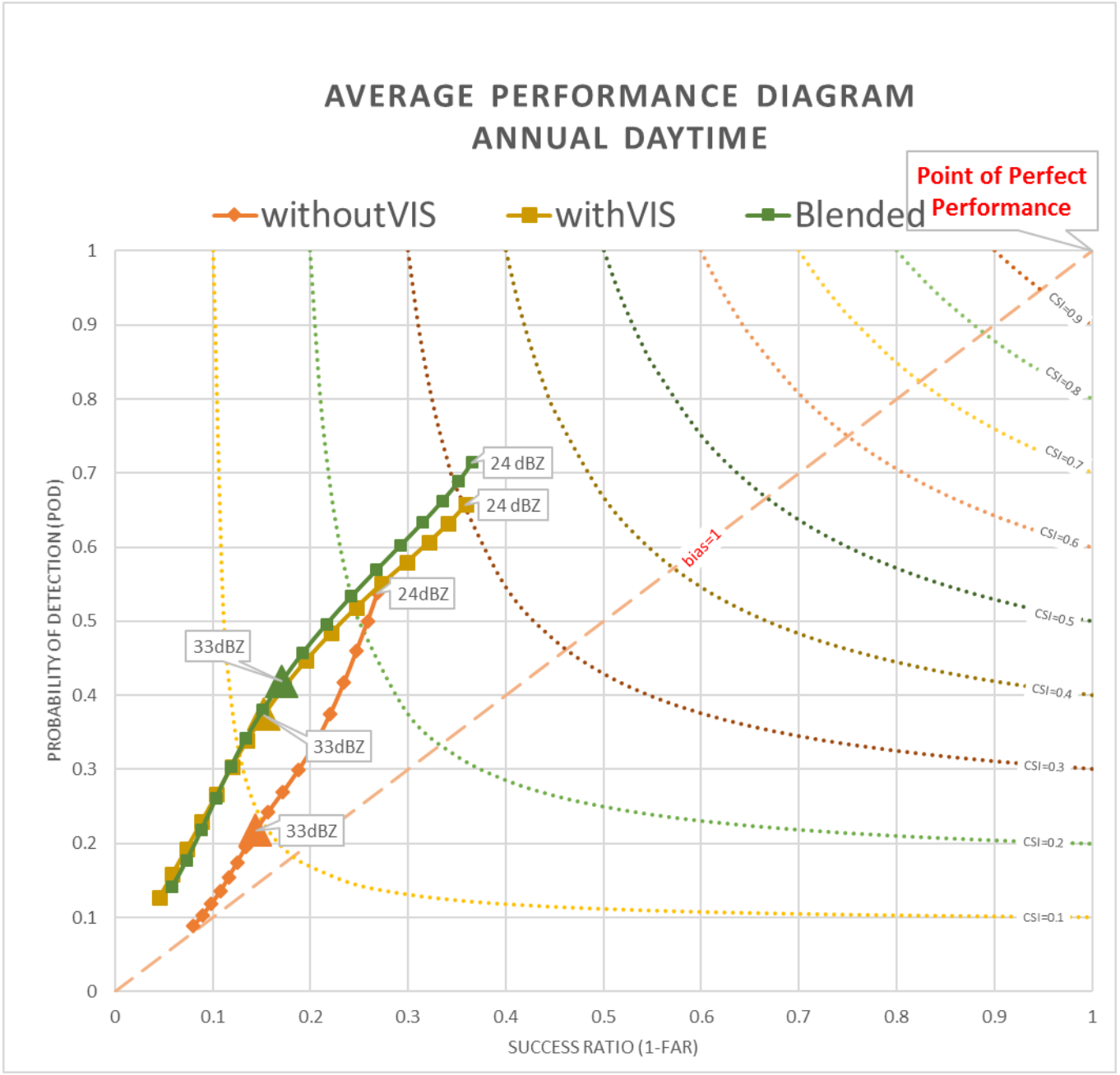
2017/08/23 09:00 HKT

“Reflectivity” of Super Typhoon Hato (1722)



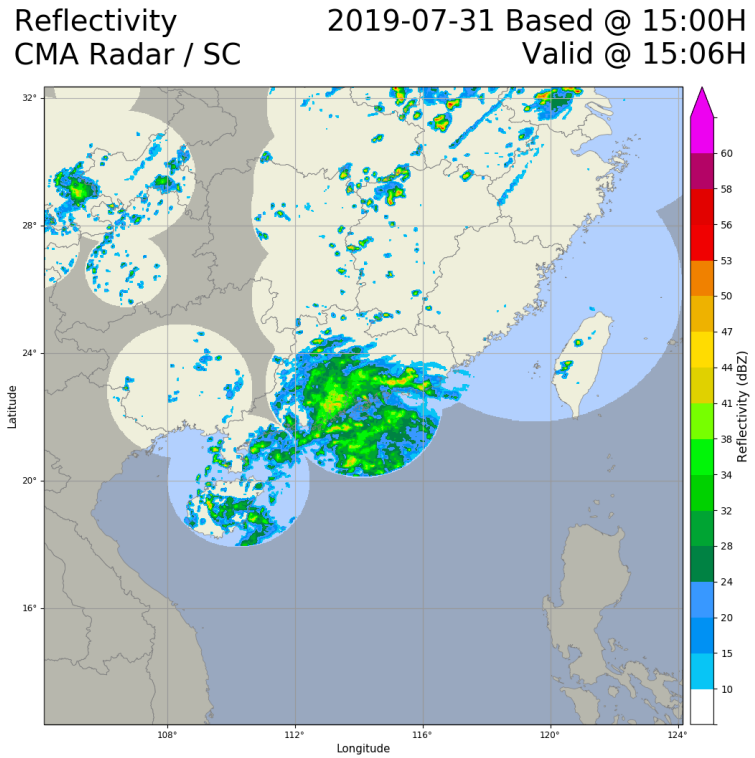
Verification

- Period: July 2015- June 2016 (12 months)
  - Odd Hours
  - On-the-hour
  - Daytime
- Results
  - POD at 24 dBZ > 70%
  - POD at 33 dBZ > 40%

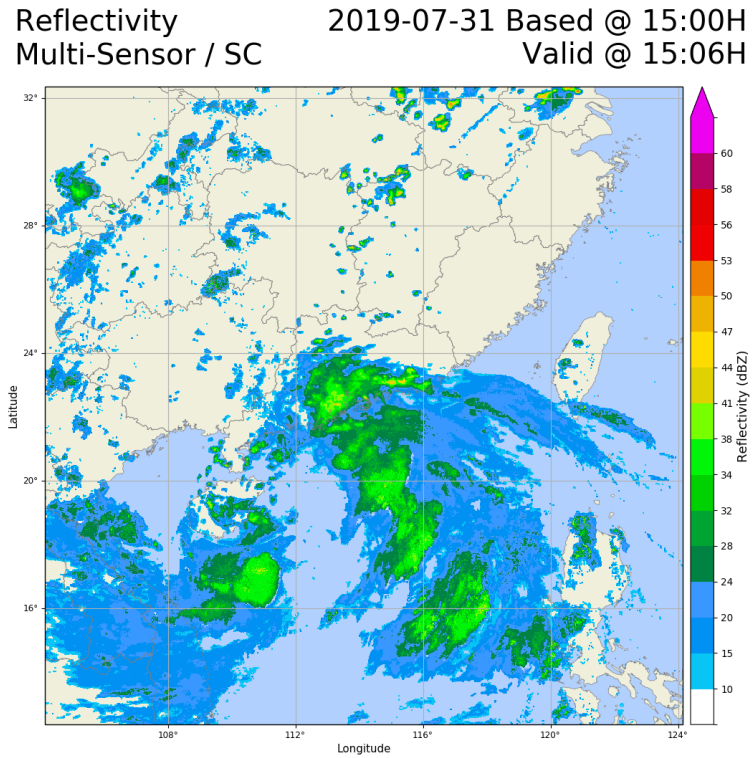


Simulate Radar Observations from Satellite Data using Neural Network

Radar Mosaic Only

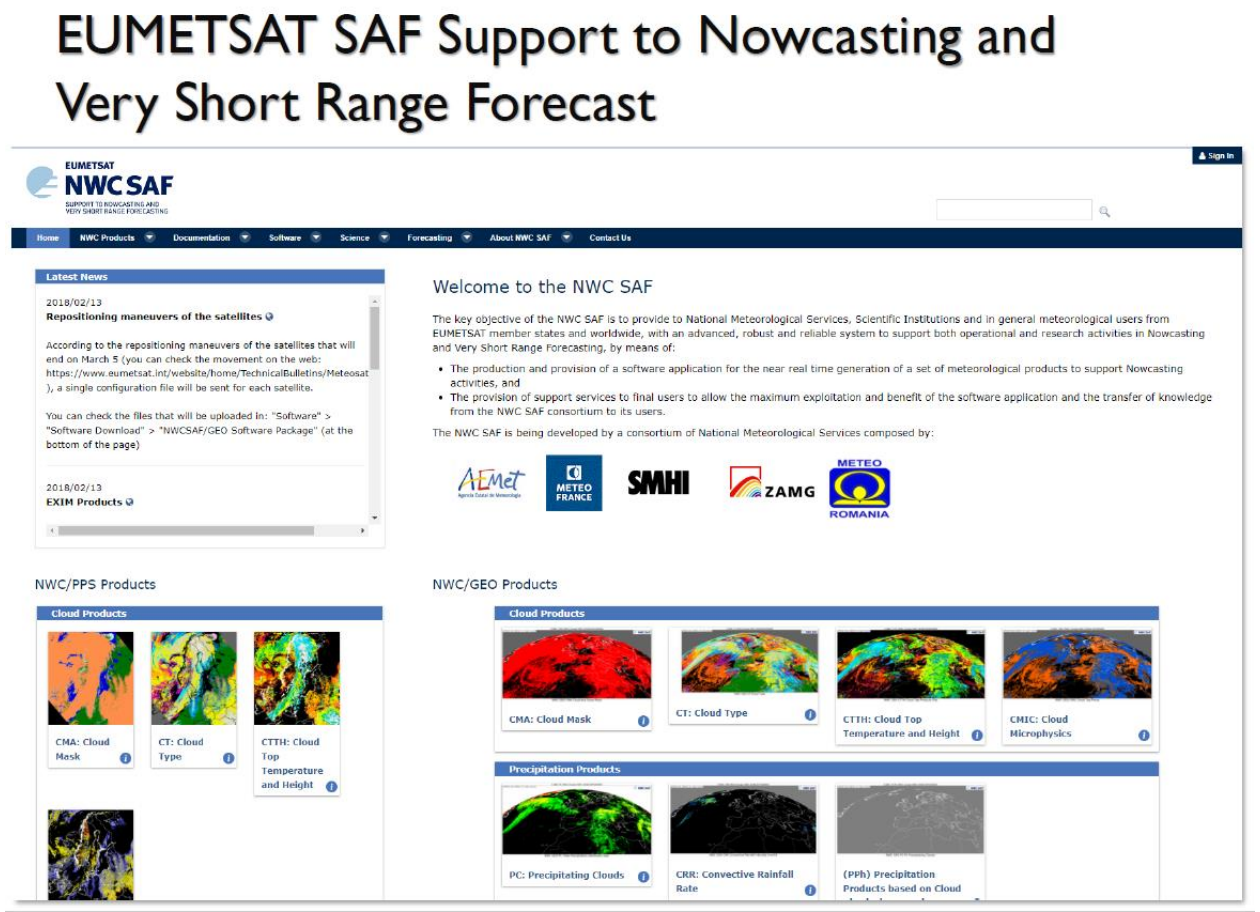


With Simulated Reflectivity

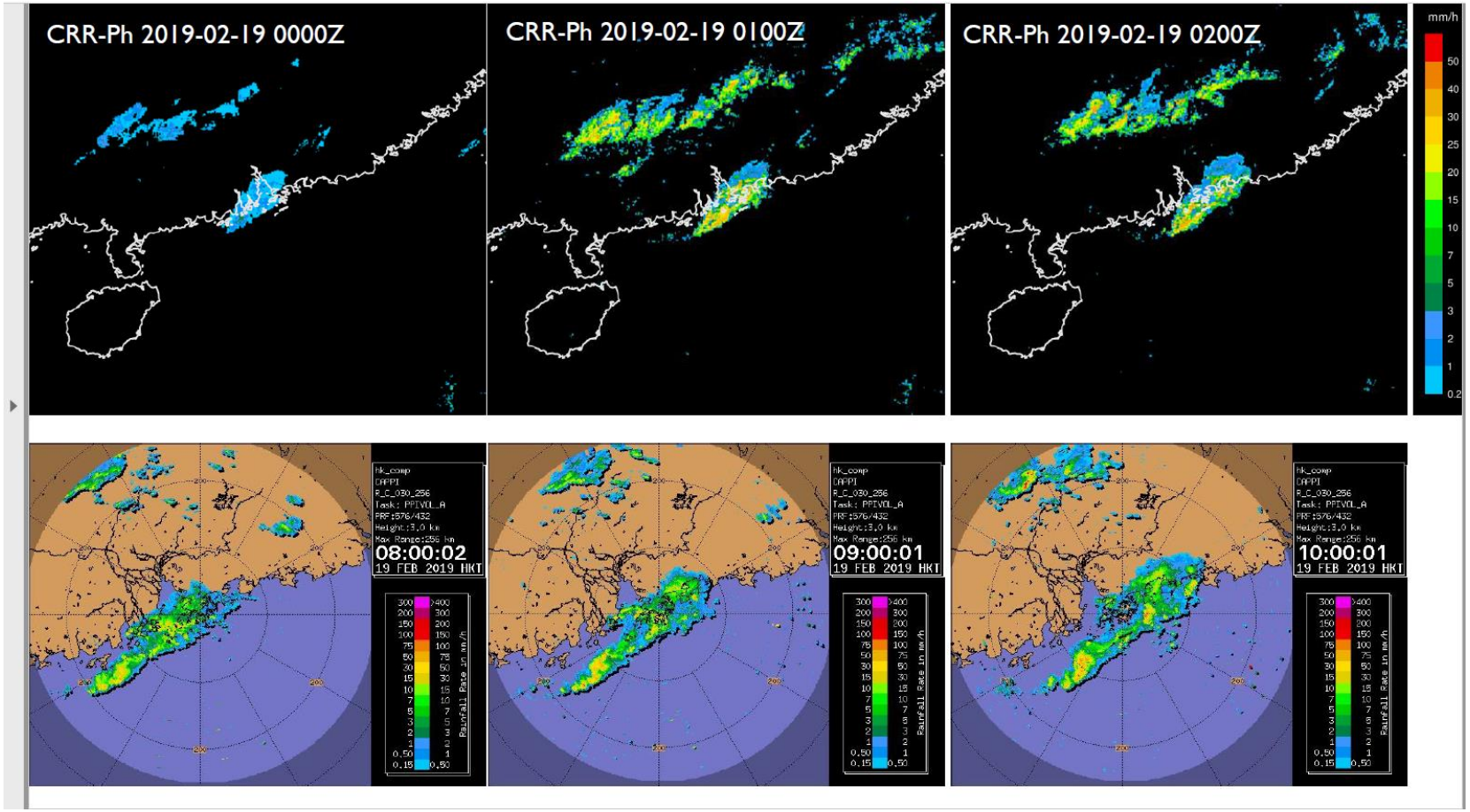


More on
Satellite Nowcast Applications

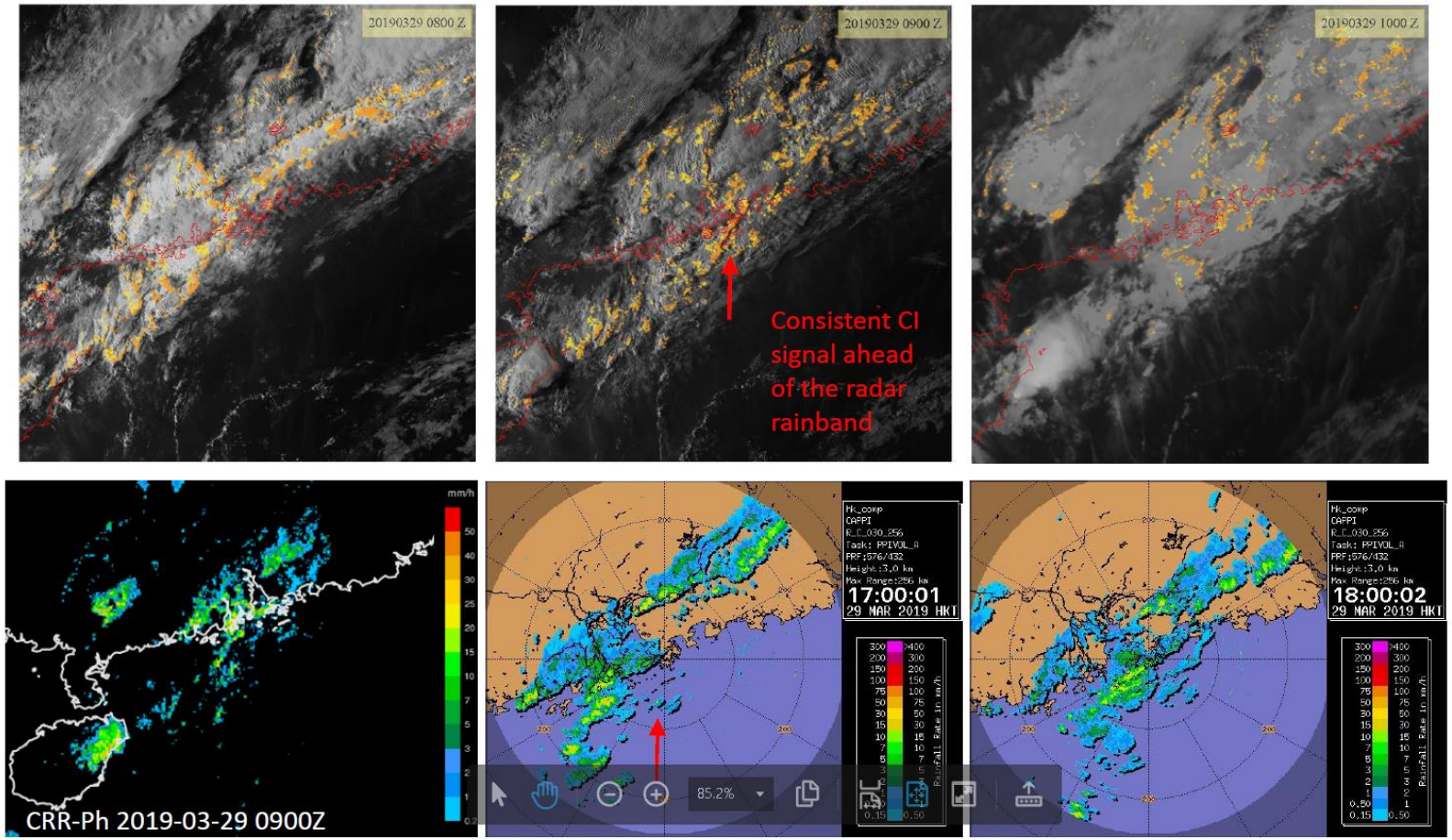
EUMETSAT NWCSAF



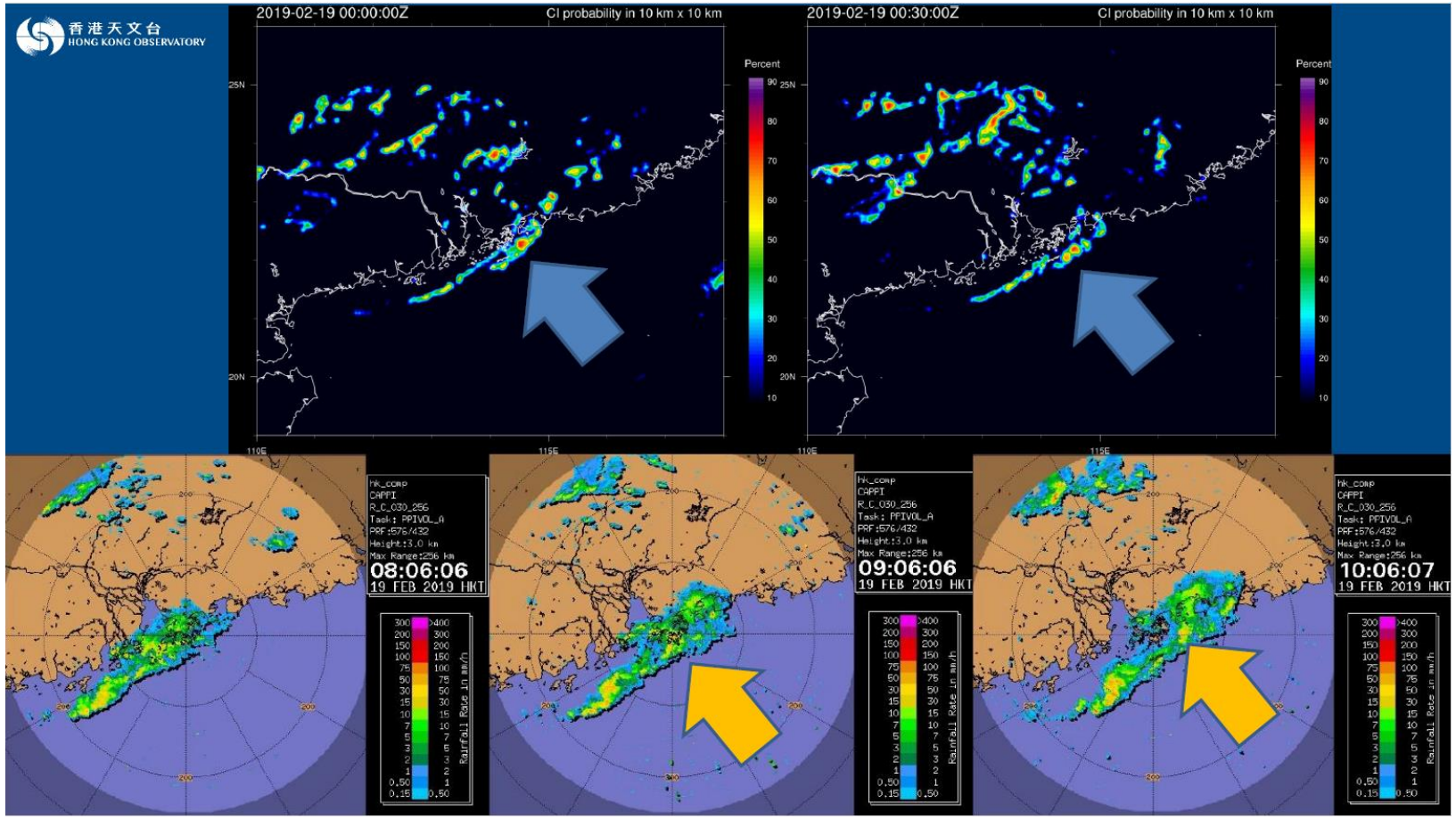
Convective Rainfall Rate from Cloud Physical Properties (CRR-Ph)



Convection Initiation (CI)



CI Probabilistic Guidance



High Resolution Wind