Radar Applications in Tropical Cyclone and Extreme Weather Monitoring and Nowcasting Part I

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TCRG Roving Seminar 2018
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Content

- Introduction of Radar Principle
- Radar Applications in Tropical Cyclone
  - o TC Positioning
  - o Hot Tower
  - o TC Wind Estimation
  - o Other Possible Scanning Strategy – 1-min Radar Rapid Scan
- Other Considerations in Using Radar

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Tai Mo Shan Weather Radar Station

Scanning Modes

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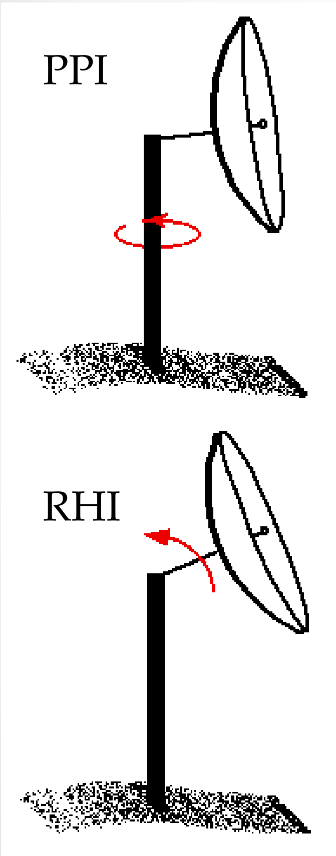
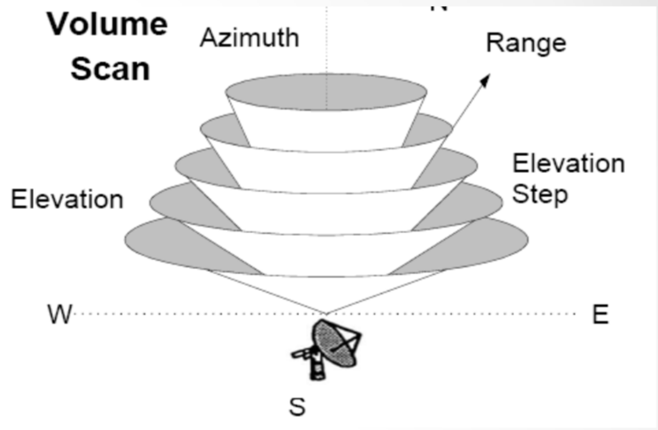
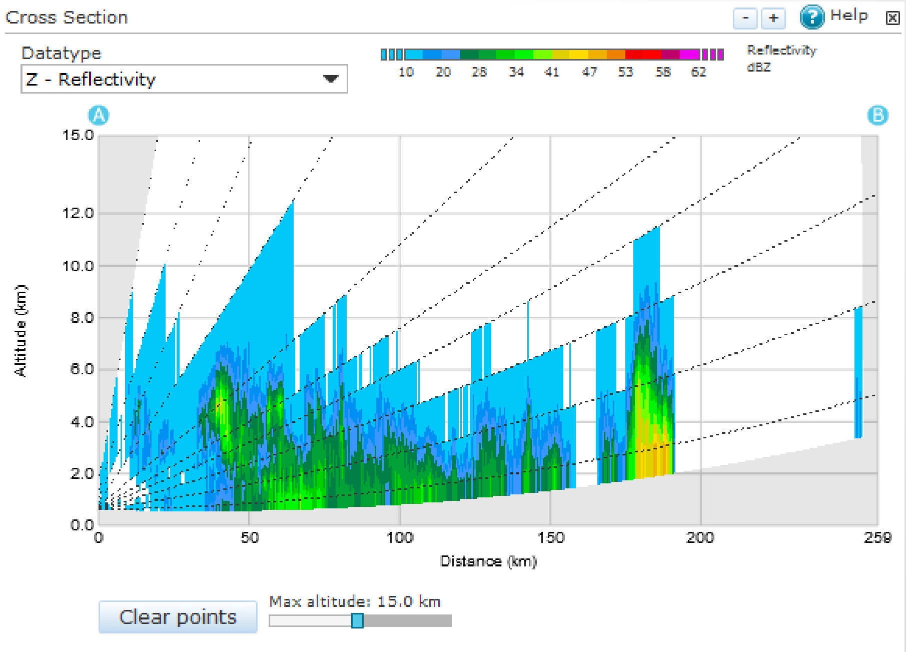


- Two main types of scans
- Plan Position Indicator (PPI)
  - Radar holds at certain elevation and rotates about the vertical axis
  - Horizontal storm distribution
- Range Height Indicator (RHI)
  - Radar holds a certain azimuth angle and tilts up/down
  - Finer vertical storm structure

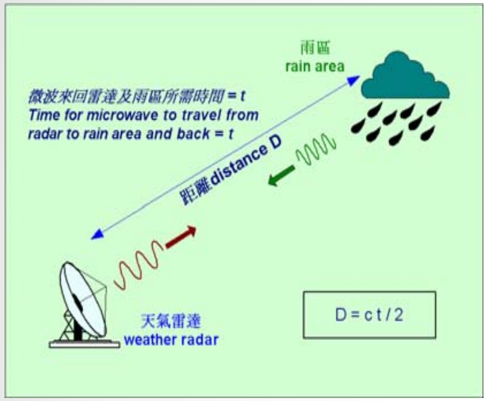
Volume Scan

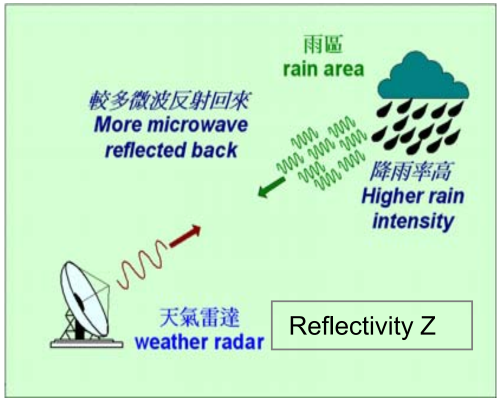
- A volume scan composed of multiple PPI scans
- Typically take 5 to 6 minutes to complete
- Filling gap between each slice by interpolation
- Level II data, raw data, base data

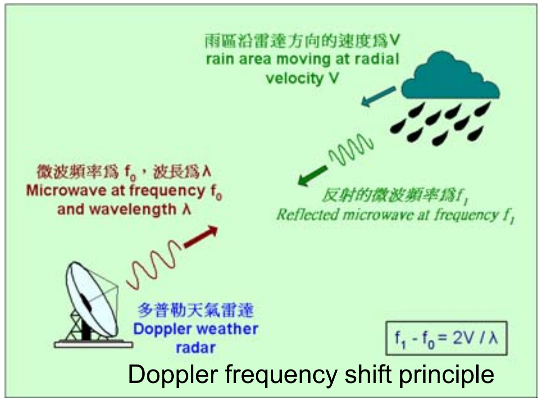


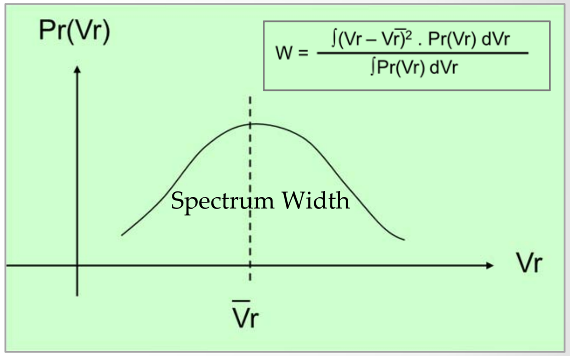


Single-polarization Weather Radar









Measure location, reflectivity, velocity and spectrum width of raindrops

Rainfall measurements

Reflectivity Z is related to the rainfall rate R by an empirical relation, Z-R relation:

$$Z = a\,R^{b}$$

For stratiform clouds, the relation is called Marshall-Palmer relation:

$$Z = 200\,R^{1.6}$$

Image of Reflectivity (Z) of HKO radar

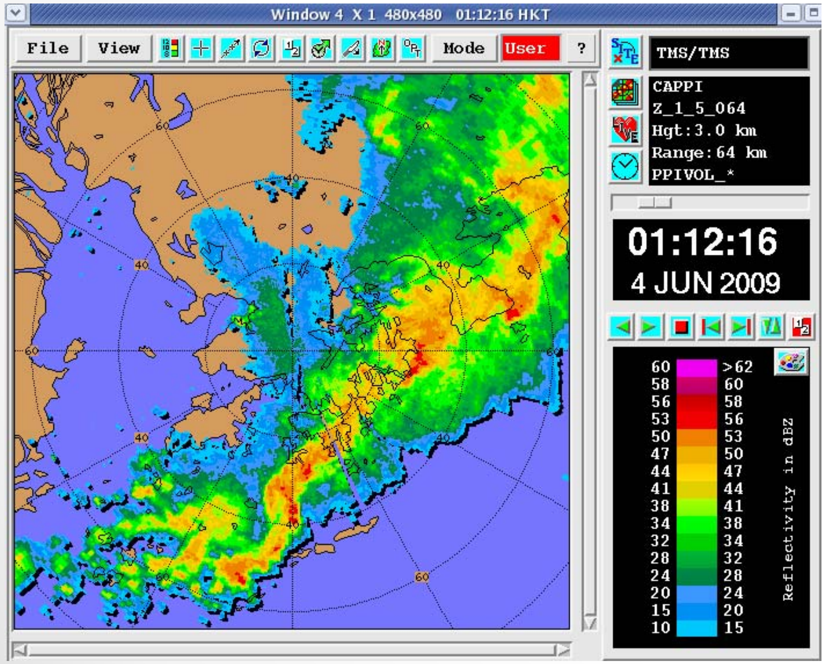
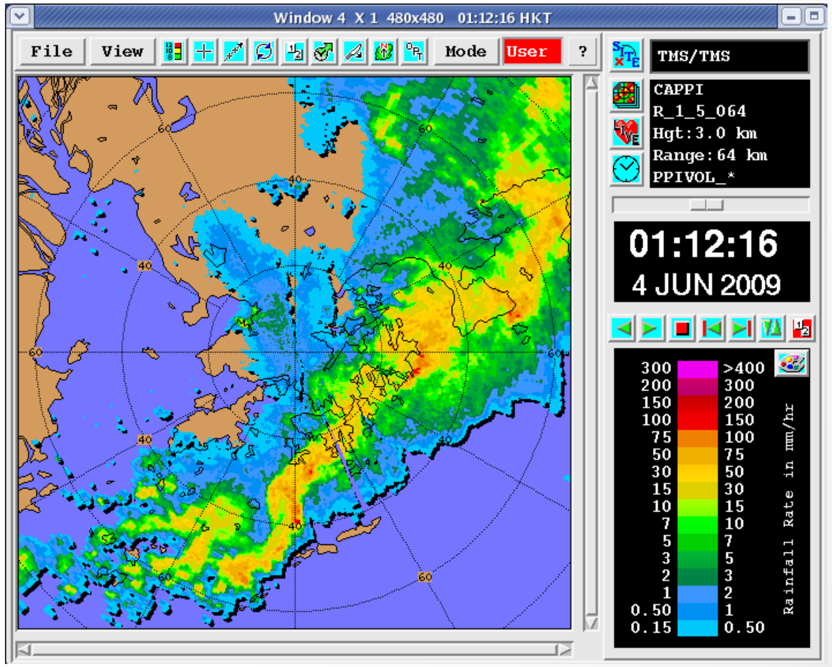
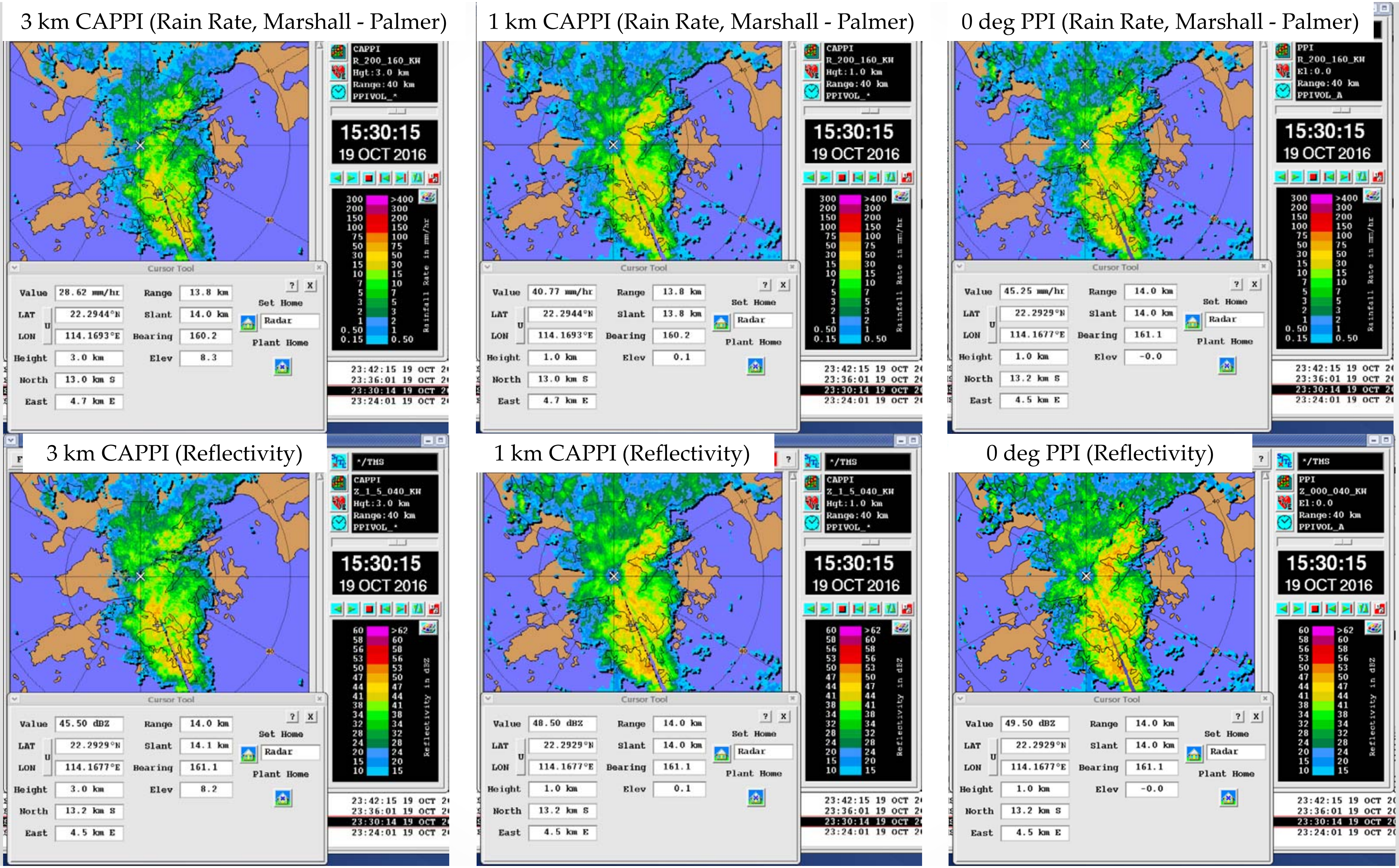


Image of Rainfall rate (R) of HKO radar using Marshall-Palmer relation





3 km CAPPI (Rain Rate, Marshall - Palmer)
1 km CAPPI (Rain Rate, Marshall - Palmer)
0 deg PPI (Rain Rate, Marshall - Palmer)
3 km CAPPI (Reflectivity)
1 km CAPPI (Reflectivity)
0 deg PPI (Reflectivity)
15:30:15
19 OCT 2016
Cursor Tool
Rainfall Rate in mm/hr
Reflectivity in dBZ

Nyquist Velocity

- Nyquist velocity or maximum unambiguous velocity
- The maximum range of radial velocity that can be observed without ambiguity by a Doppler radar.
- Doppler Velocity values in excess of Vmax are folded.
- The true values are offset by mulitiples of ± 2Vmax

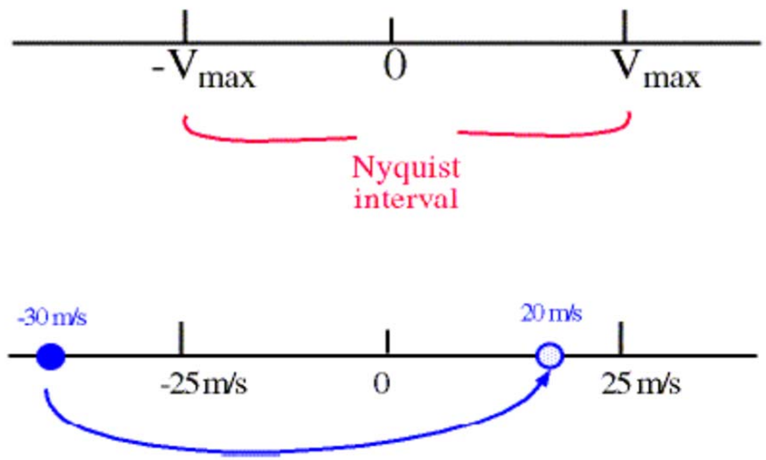
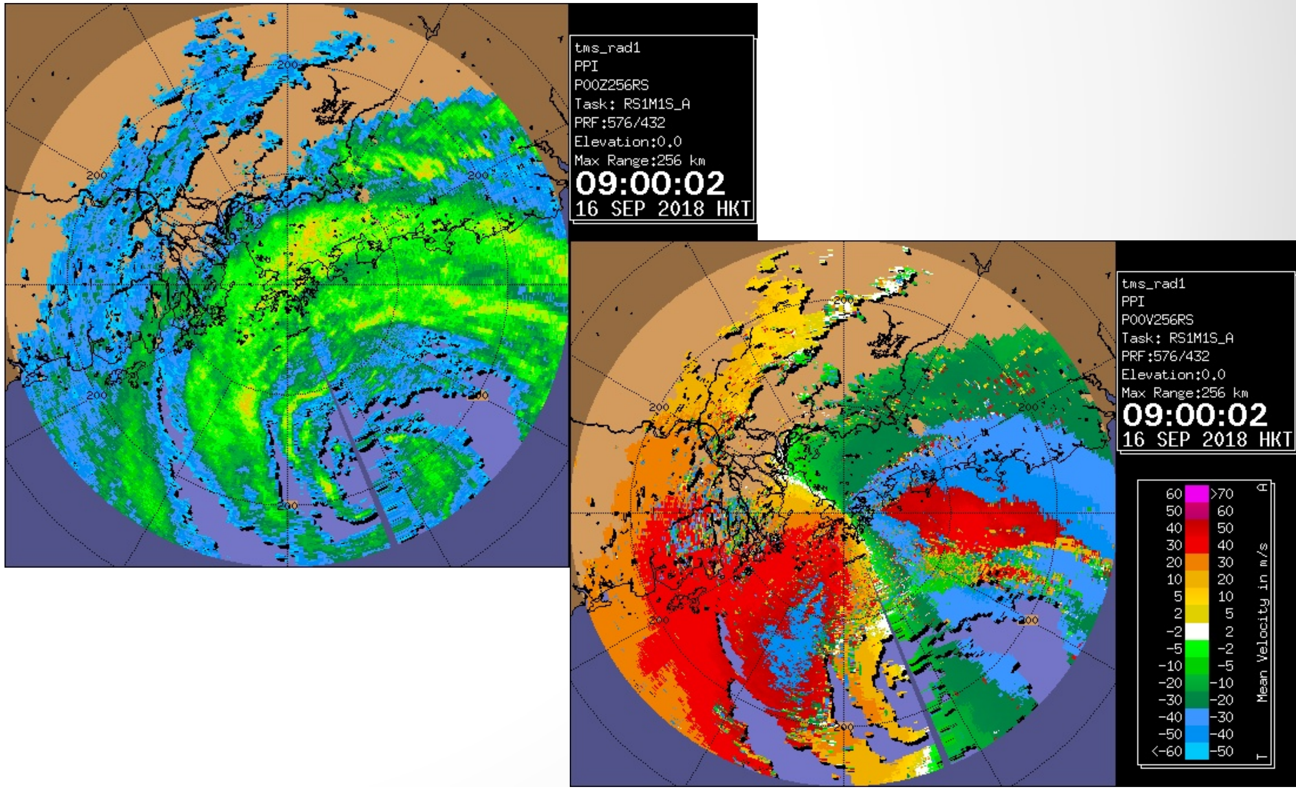
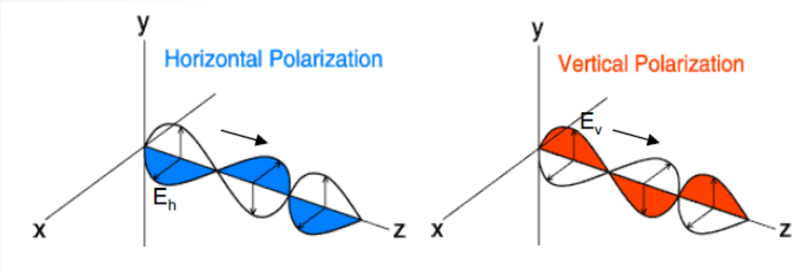


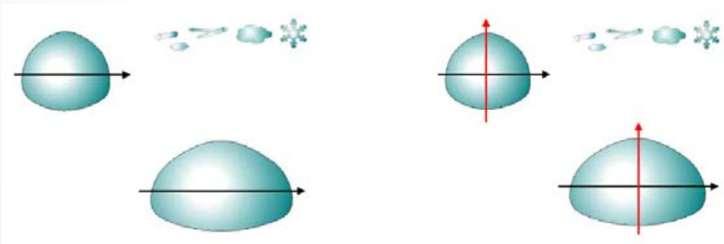
Figure 37: Velocity Folding or Aliasing.



Dual-polarization Radar

- Dual-polarization radar transmit and receive both horizontal and vertical polarized pulses.





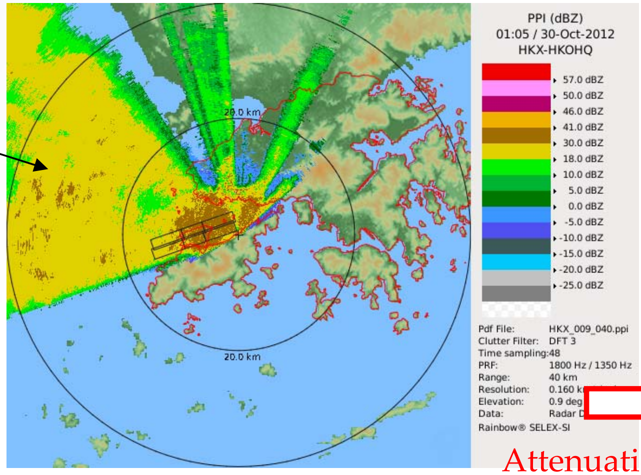
Single-polarization Dual-polarization

Raw Data

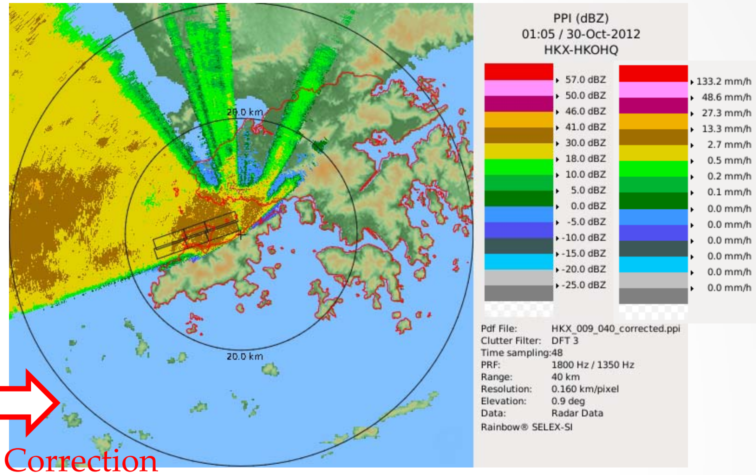
- Reflectivity (Z)
- Velocity (V)
- Spectral Width (W)
- Differential Reflectivity (ZDR)
- Differential Phase (Φ_{DP})
- Specific Differential Phase (K_{DP})
- Correlation Coefficient (ρ_{hv})

Example

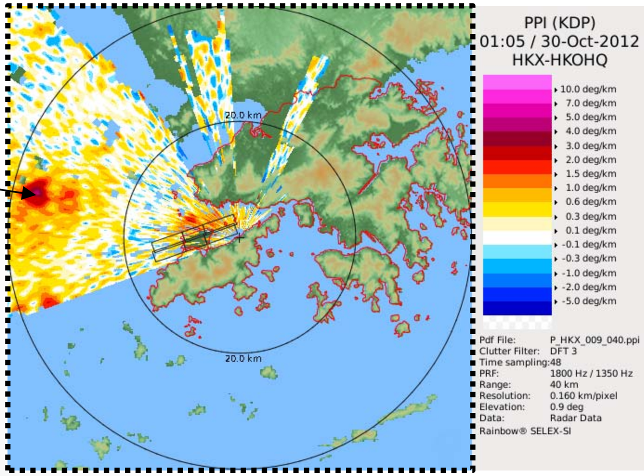
Uniform
Rain Rate

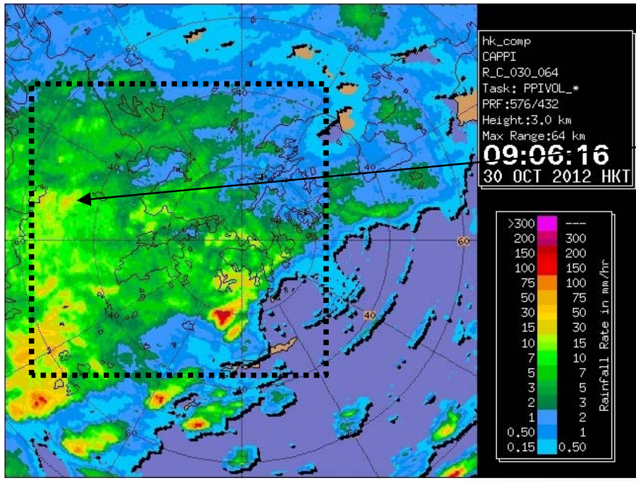


Attenuation Correction



Higher KDP,
Higher Rain Rate

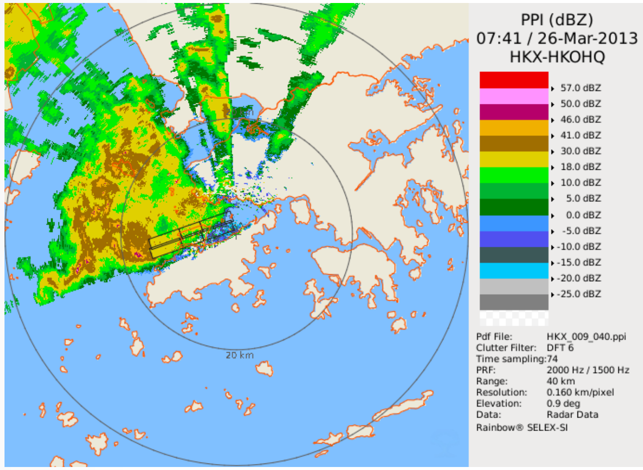


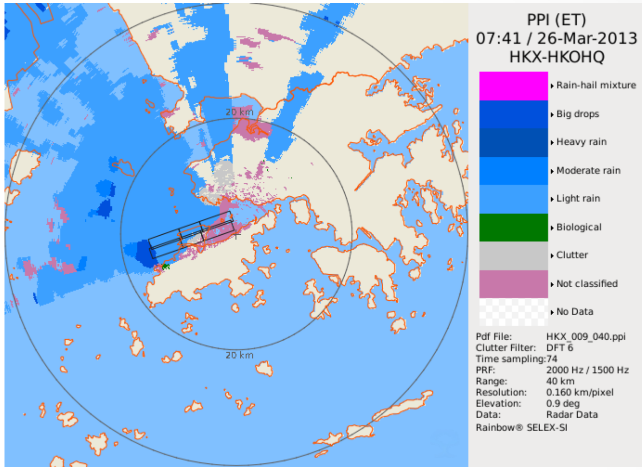


Higher Rain Rate
in TMSWR

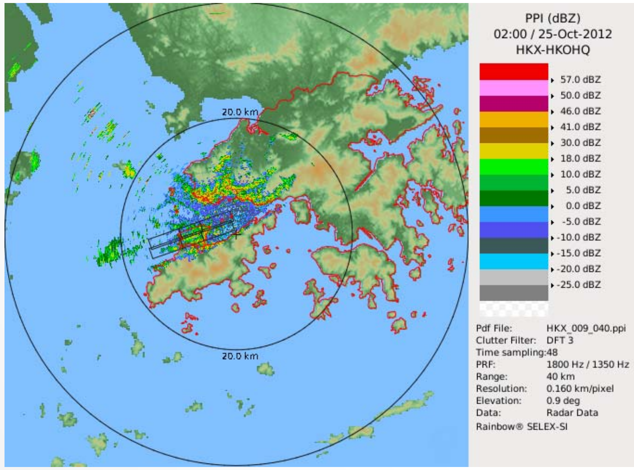
Hydrometeor Classification

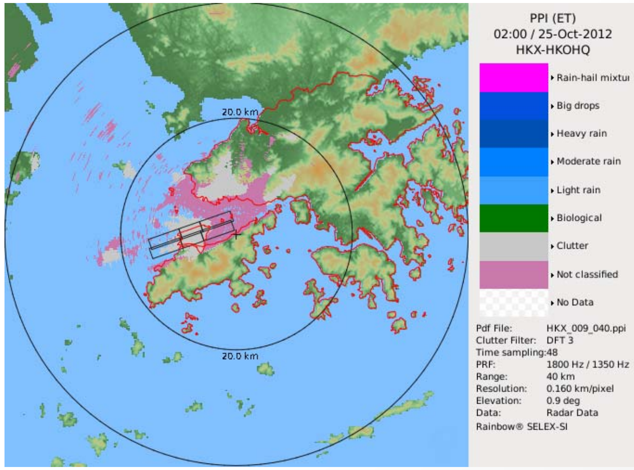
Case I: Rainstorms





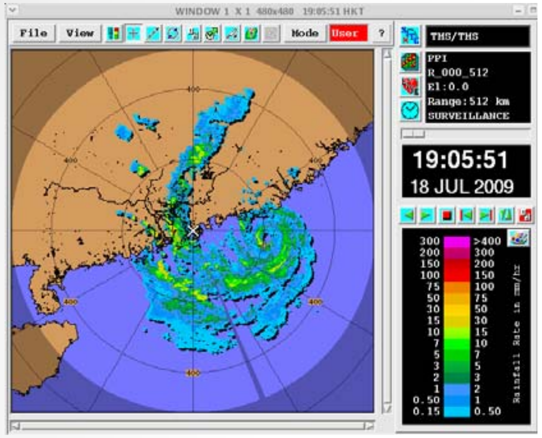
Case II: Clutters under fine weather



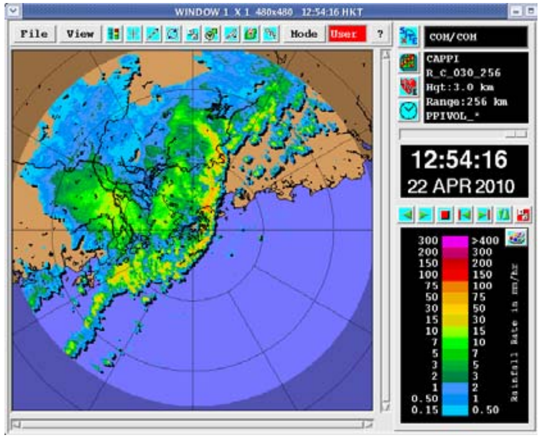


Common Radar Products

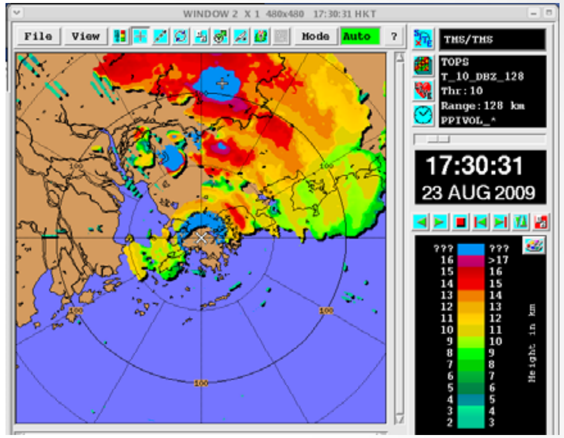
Common Radar Products



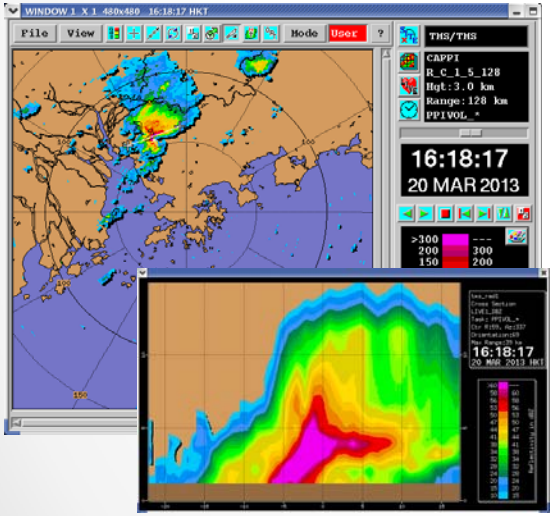
PPI (Plan Position Indicator)



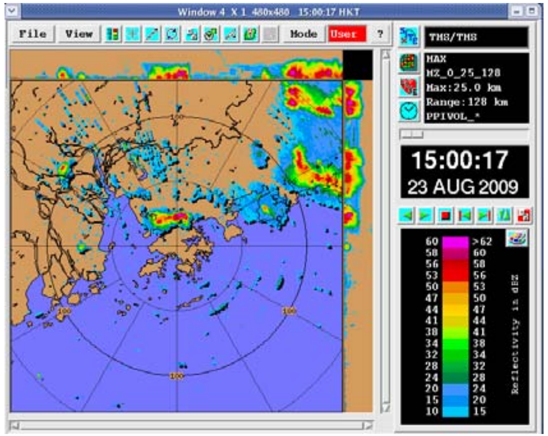
CAPPI (Constant Altitude PPI)



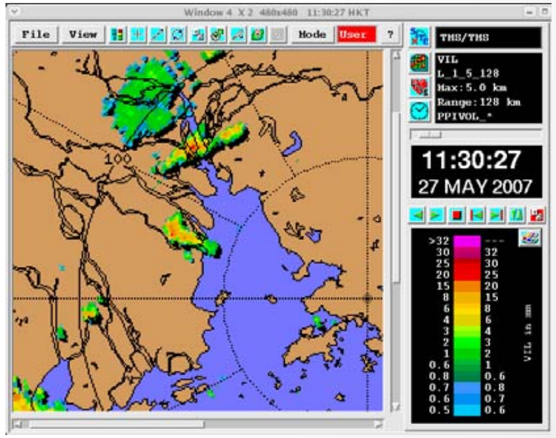
TOPS
height of echo top of 10 dBZ surface



Cross-section

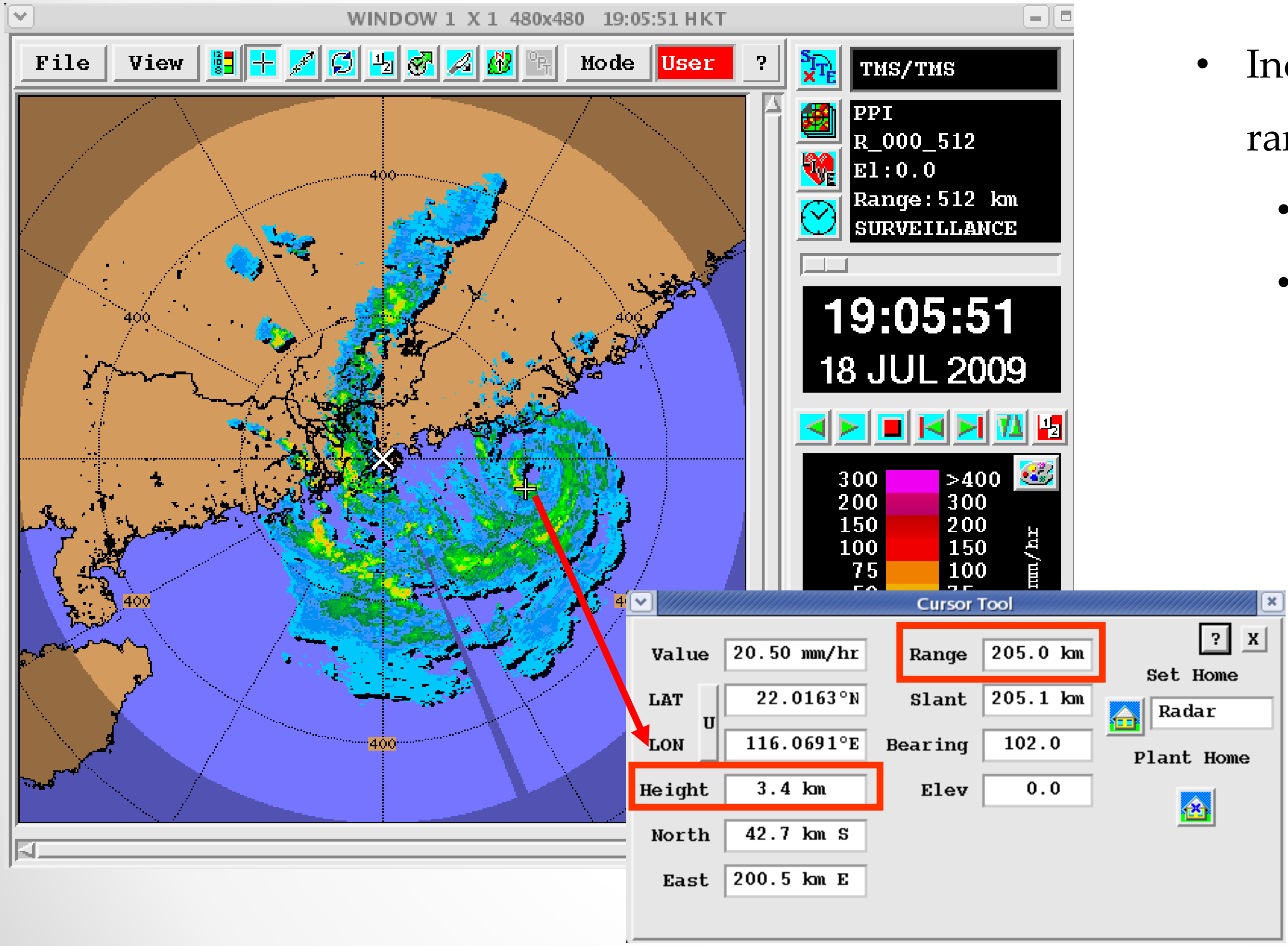


MAX
(the maximum reflectivity above each pixel)

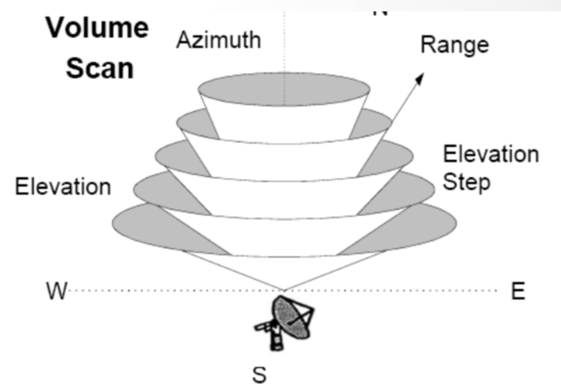


VIL (Vertical Integrated Liquid)
High VIL (e.g. > 20 mm) is a good indicator of severe storm and hail.

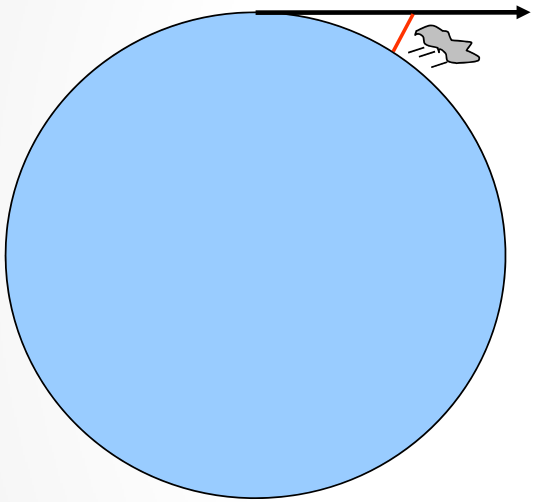
PPI (Plan Position Indicator)

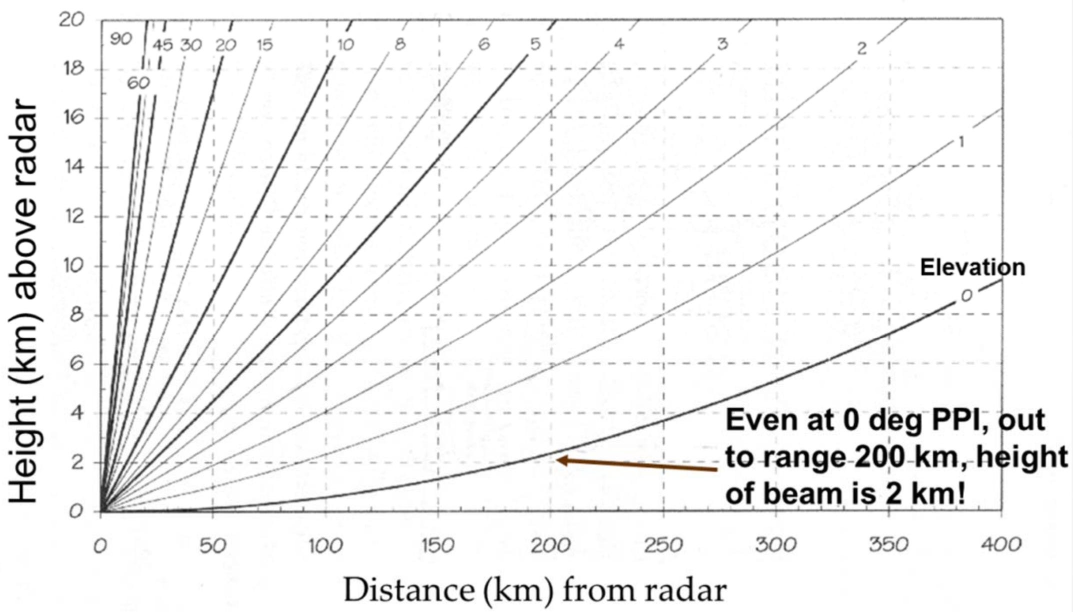


- Increasing height with increasing range
    - Scanning elevation
    - Even for 0 deg elevation PPI because of earth's curvature



Earth's curvature

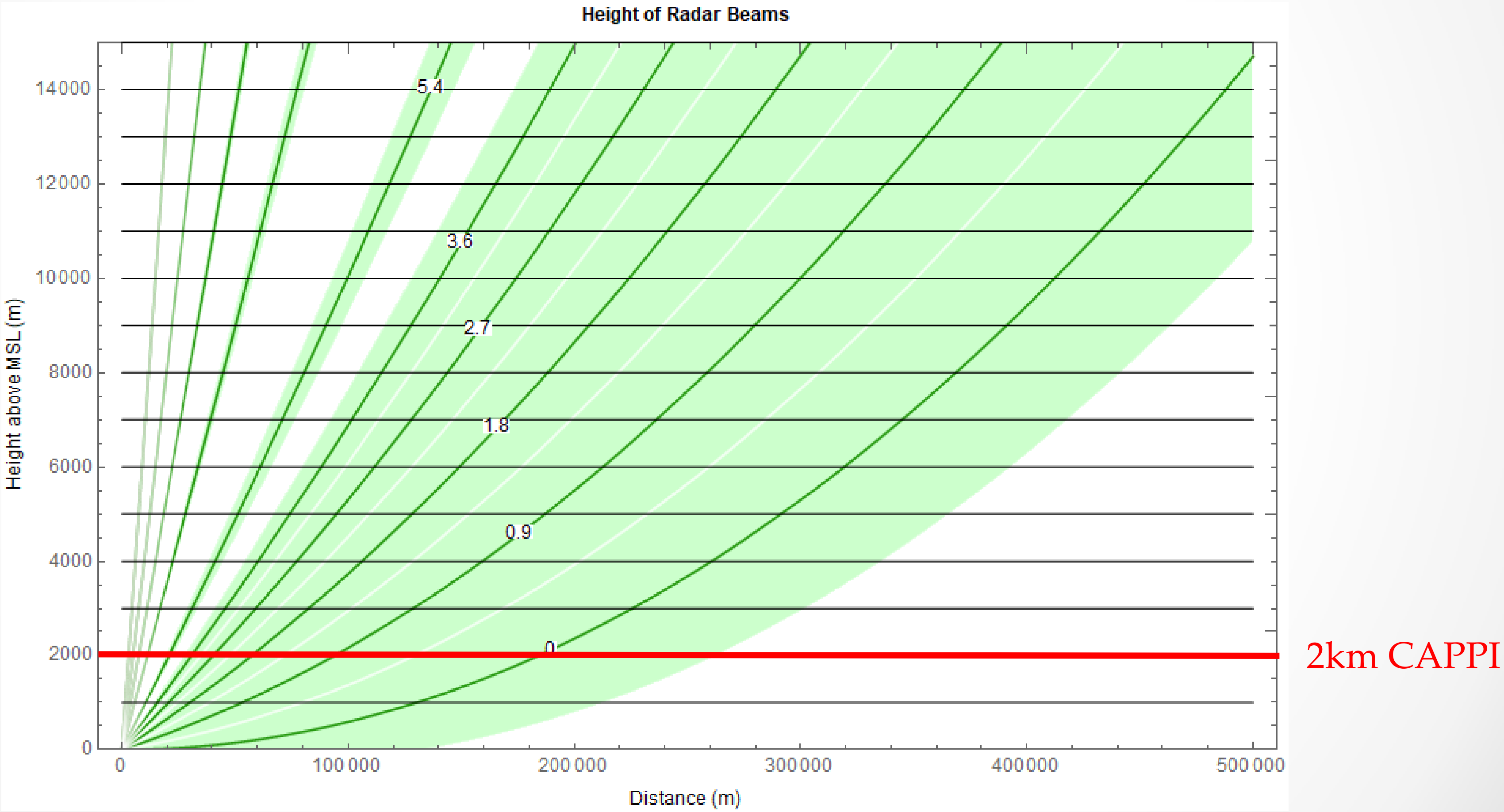




Range-height diagram. Numbers on each curve are elevation angles in degrees.

CAPPI

- Constant Altitude Plan Position Indicator



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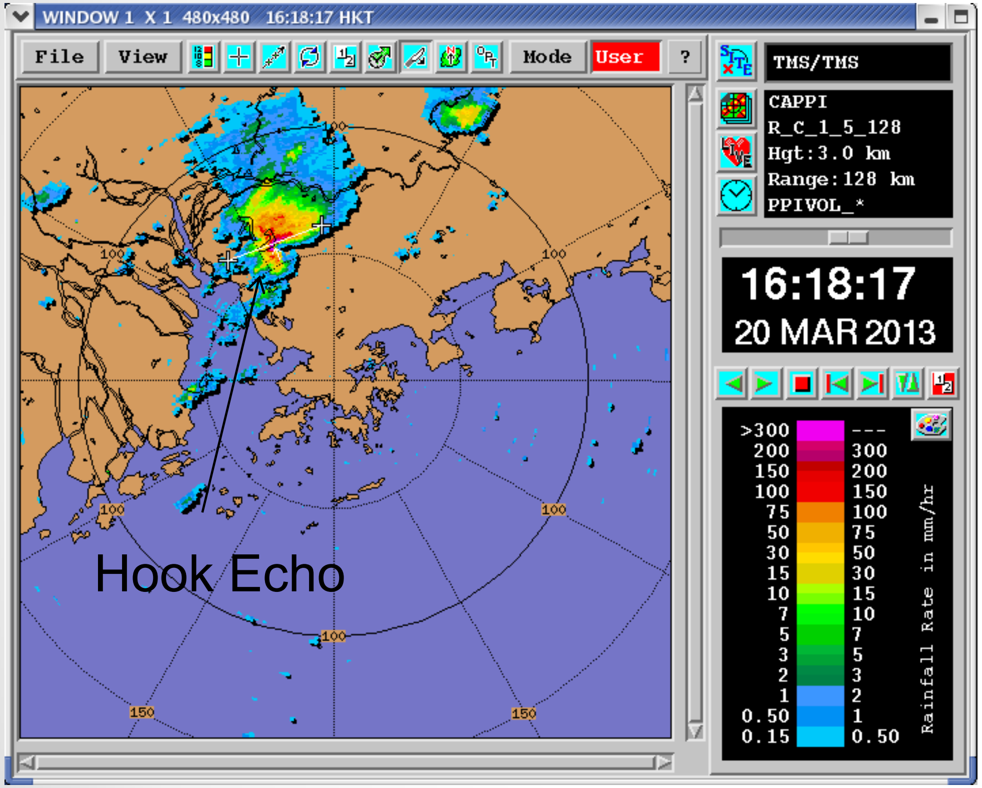
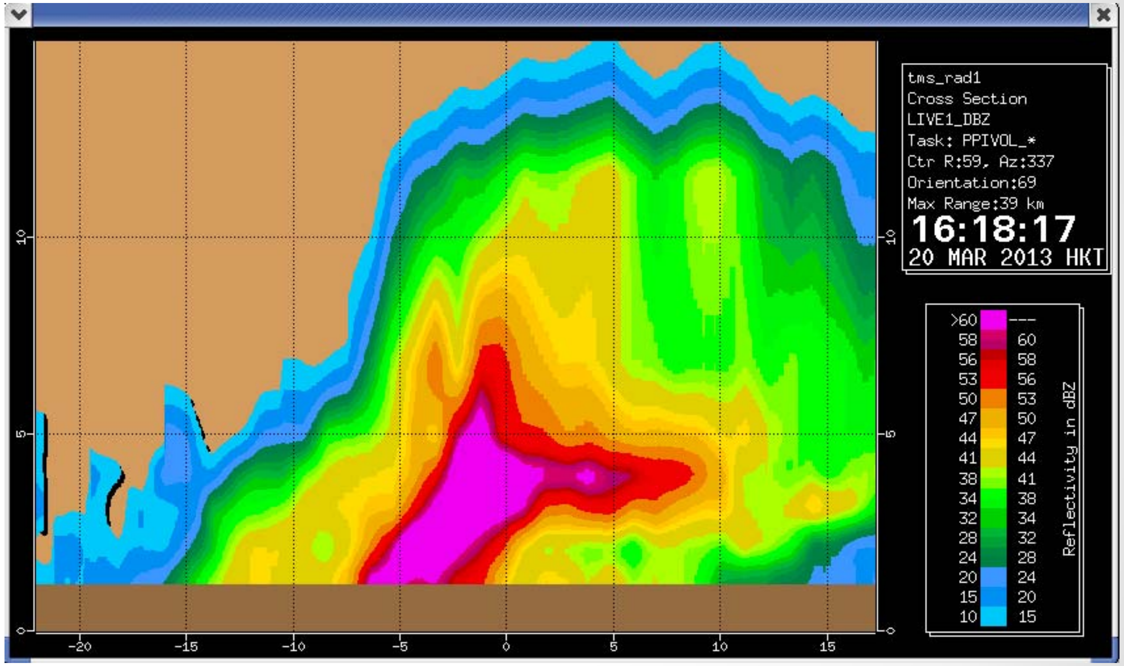
Cross-section





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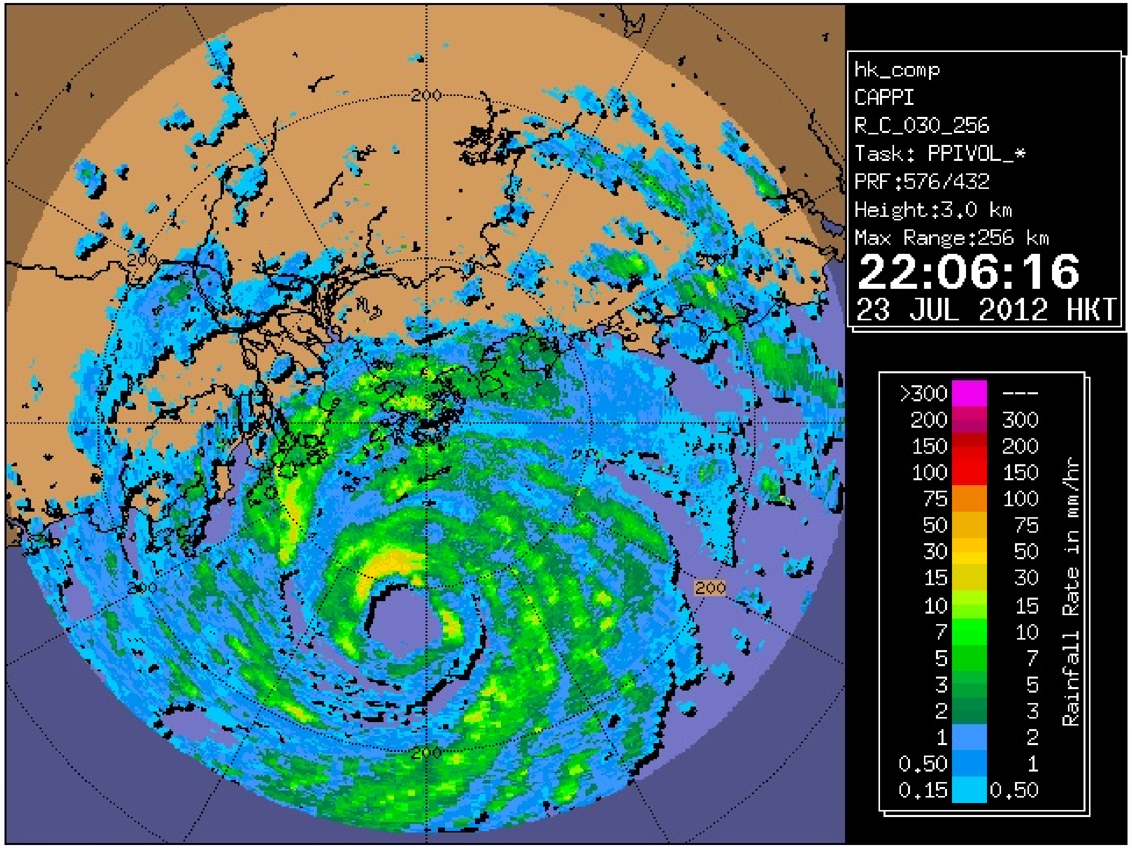
Radar Applications in Tropical Cyclone

- Positioning
- Estimation of Wind Strength
- Estimation of Rainfall Rate

TC Positioning

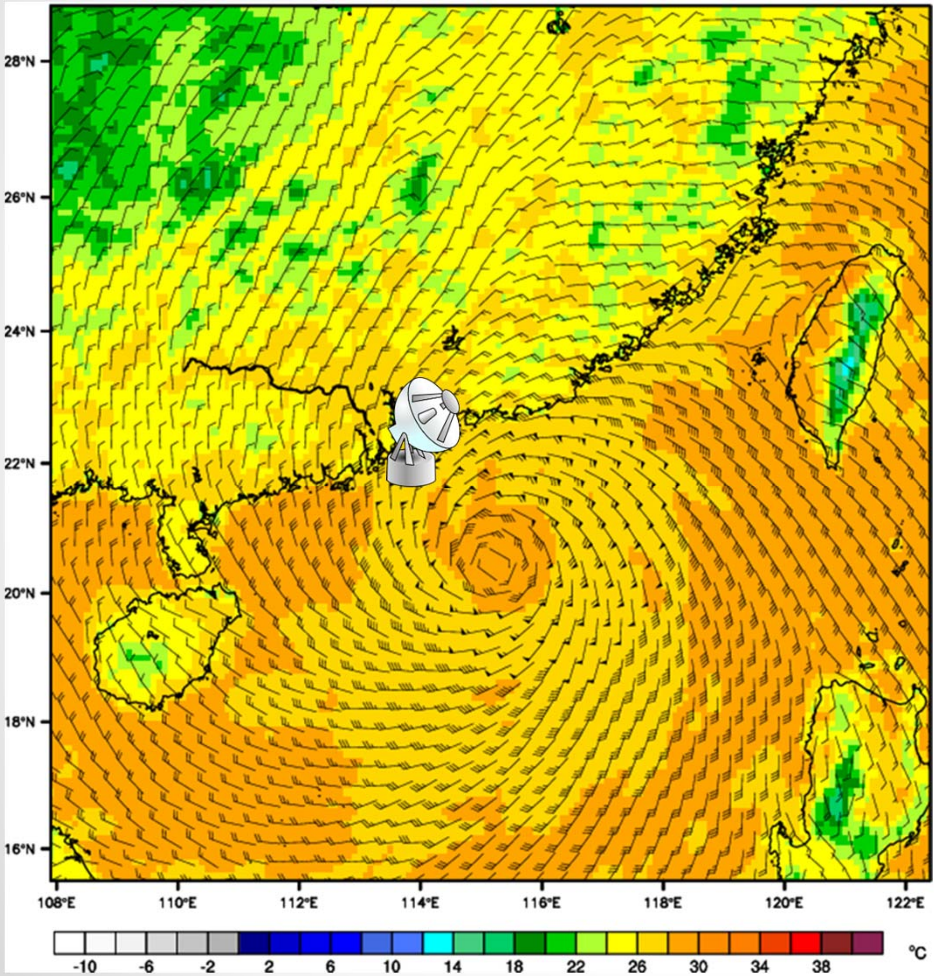
- Direct observation
- Zero isodop
- Use of spiral
- Dual Doppler wind products
- Use of mosaic imagery

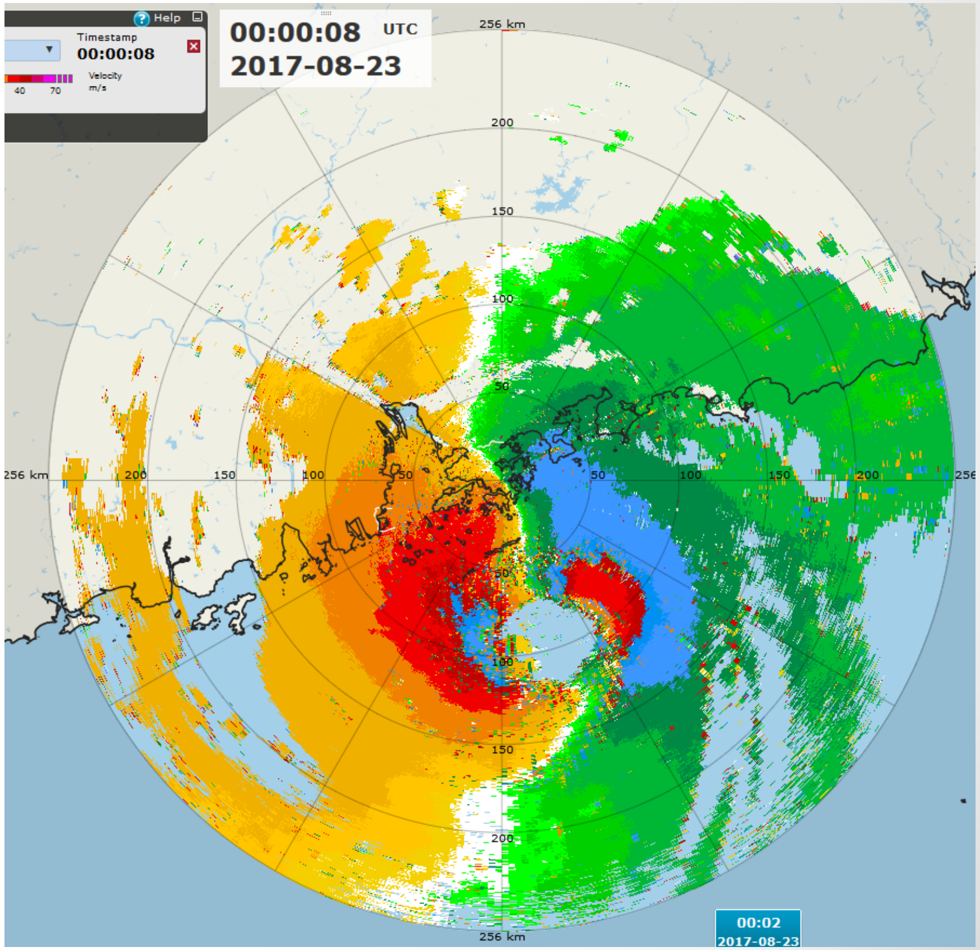
Direct Observation



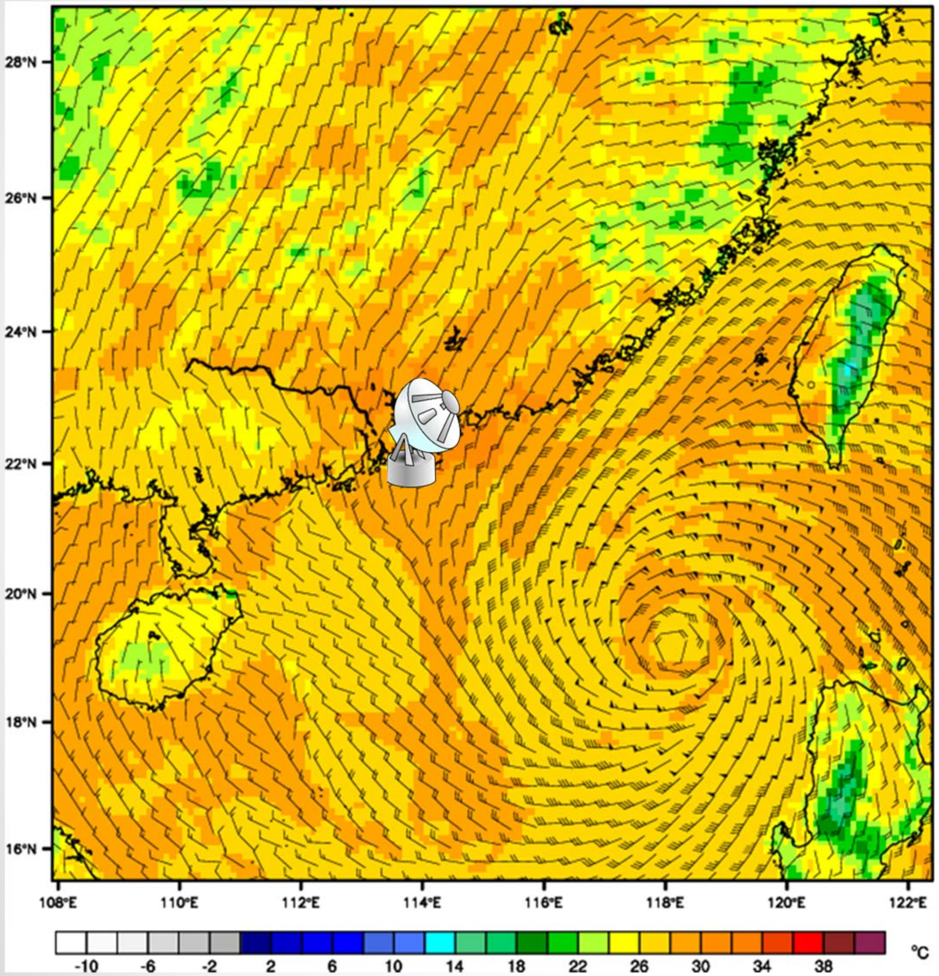
Zero Isodop

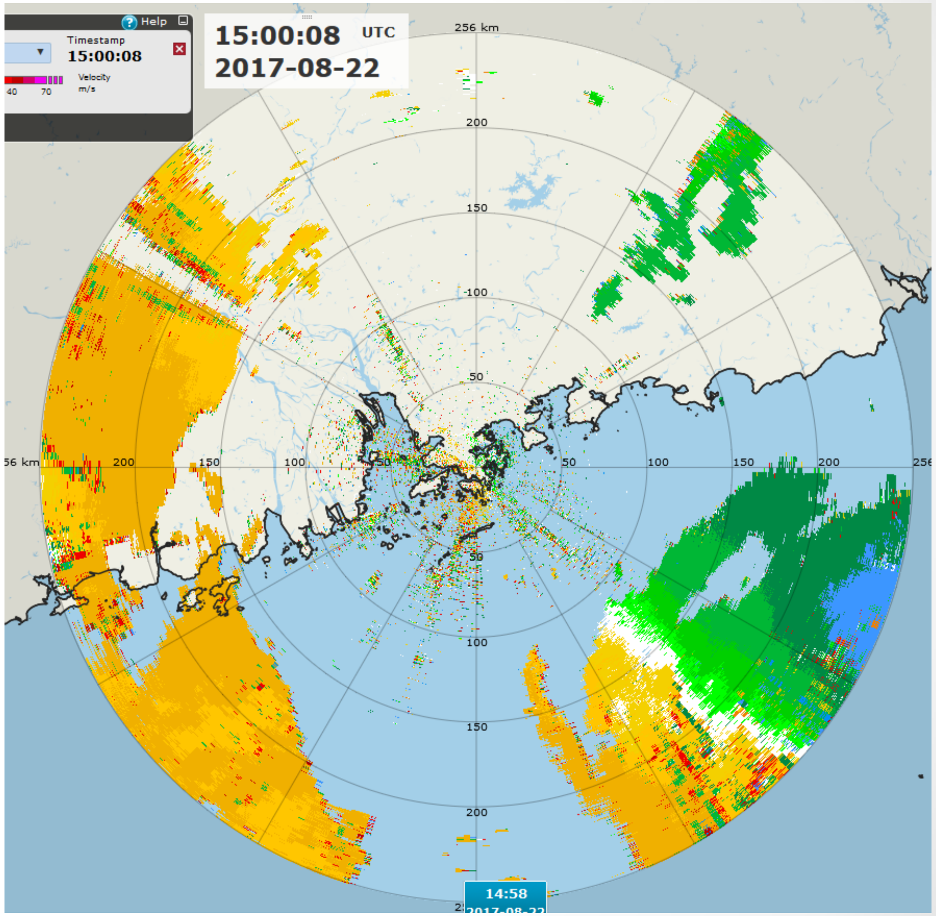
- Zero isodop, usually white in colour. Wind direction is at right angle to the zero isodop.



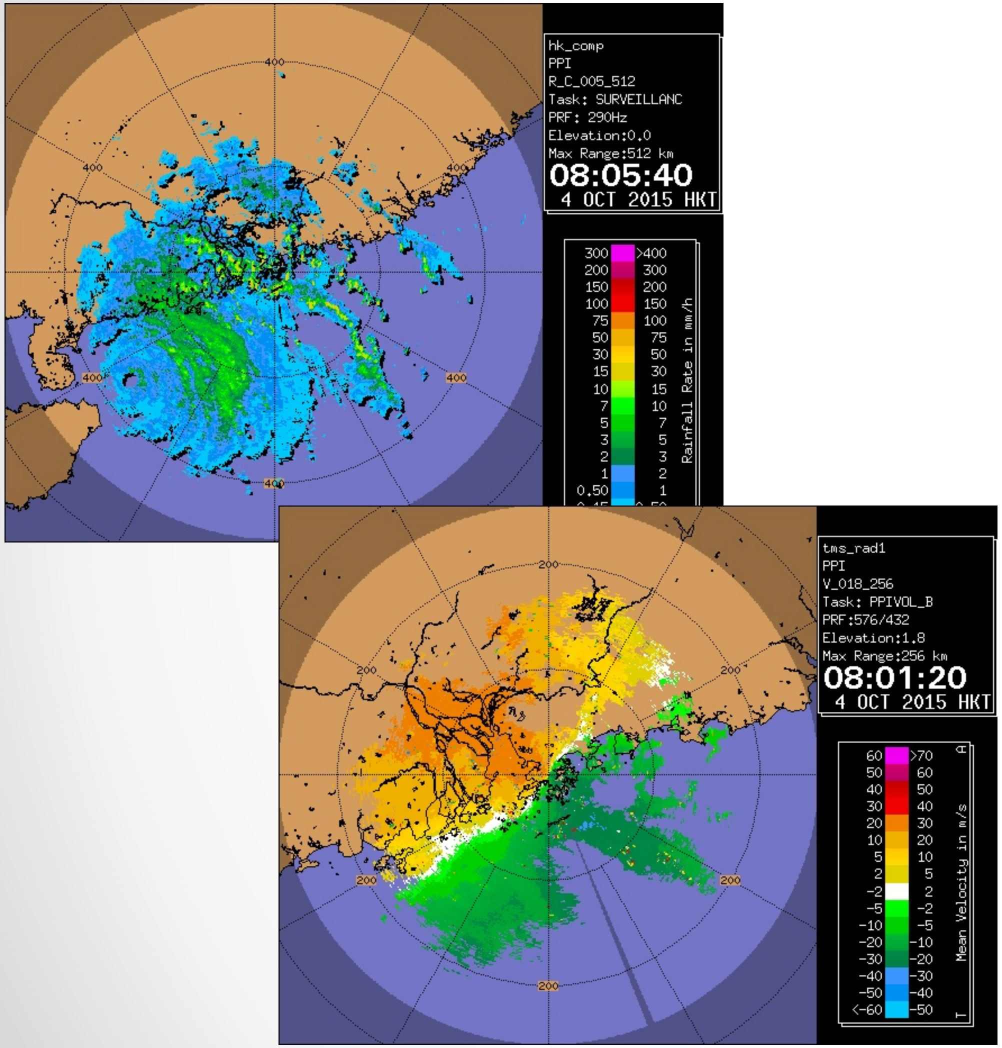


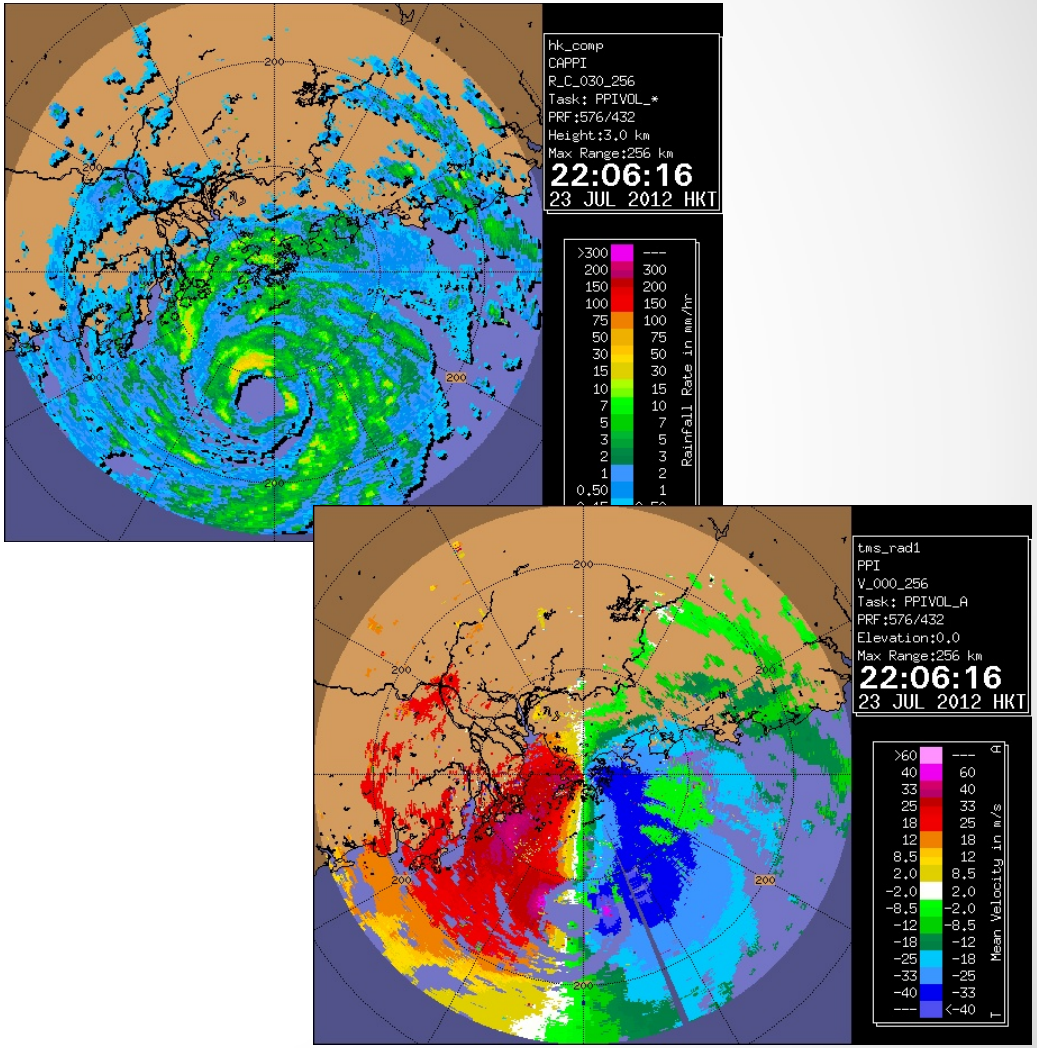
Zero Isodop


28°N
26°N
24°N
22°N
20°N
18°N
16°N
108°E
110°E
112°E
114°E
116°E
118°E
120°E
122°E
-10
-6
-2
2
6
10
14
18
22
26
30
34
38
°C

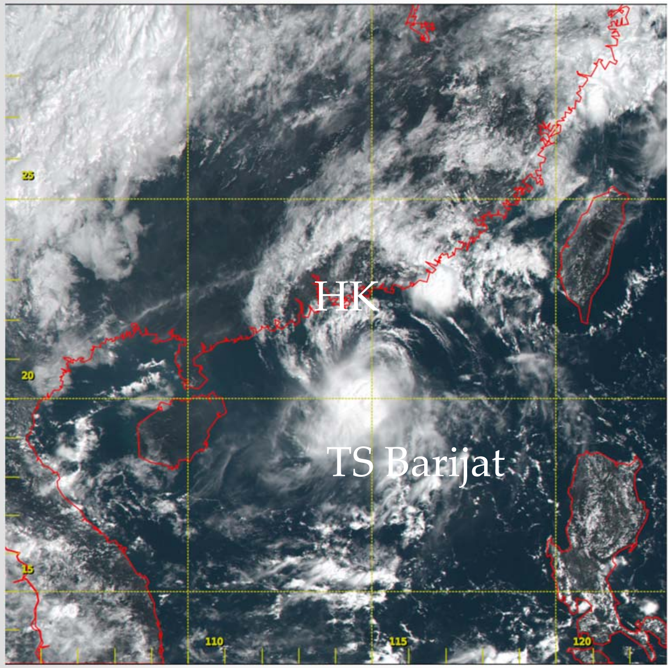

Help
Timestamp
15:00:08
Velocity
m/s
40
70
15:00:08 UTC
2017-08-22
256 km
200
150
100
50
14:58

Zero Isodop

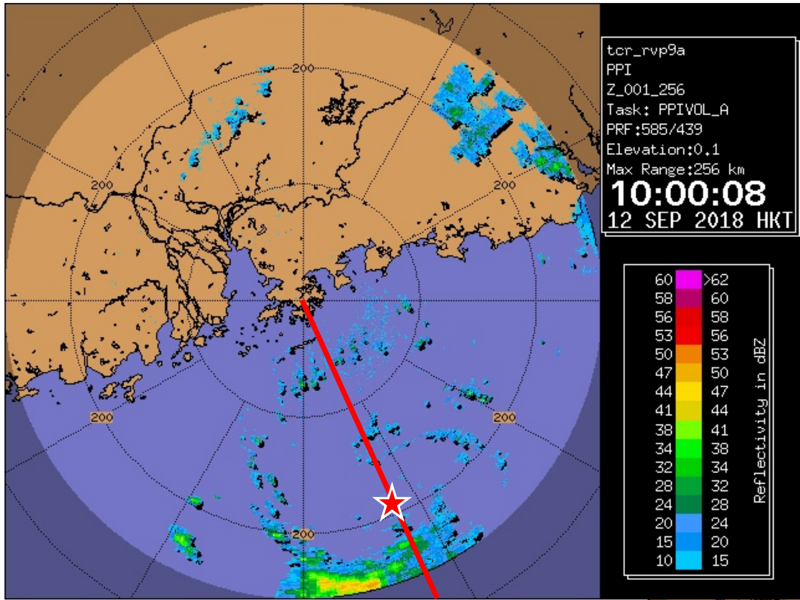

hk_comp
PPI
R_C_005_512
Task: SURVEILLANC
PRF: 290Hz
Elevation:0.0
Max Range:512 km
08:05:40
4 OCT 2015 HKT
Rainfall Rate in mm/h
tms_rad1
PPI
V_018_256
Task: PPIVOL_B
PRF:576/432
Elevation:1.8
Max Range:256 km
08:01:20
4 OCT 2015 HKT
Mean Velocity in m/s

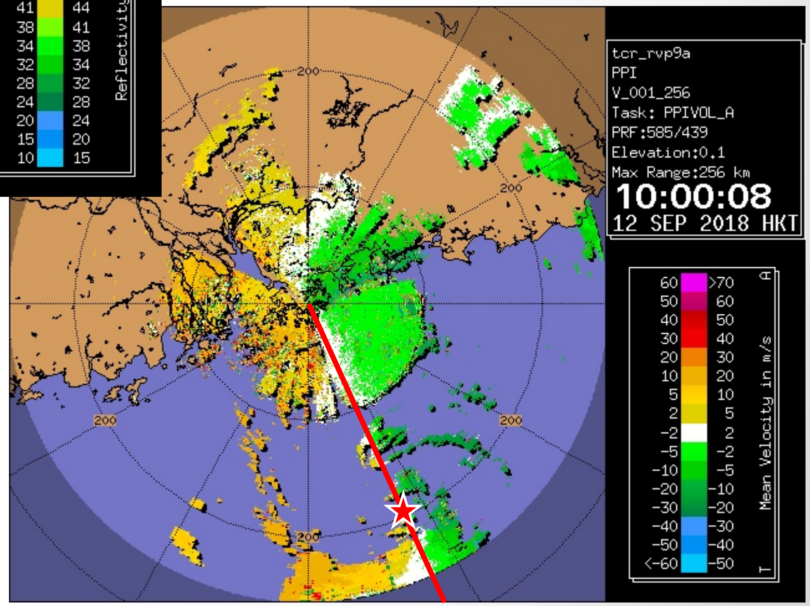

hk_comp
CAPPI
R_C_030_256
Task: PPIVOL_*
PRF:576/432
Height:3.0 km
Max Range:256 km
22:06:16
23 JUL 2012 HKT
Rainfall Rate in mm/hr
tms_rad1
PPI
V_000_256
Task: PPIVOL_A
PRF:576/432
Elevation:0.0
Max Range:256 km
22:06:16
23 JUL 2012 HKT
Mean Velocity in m/s

Weak TC - Tropical Storm Barijat

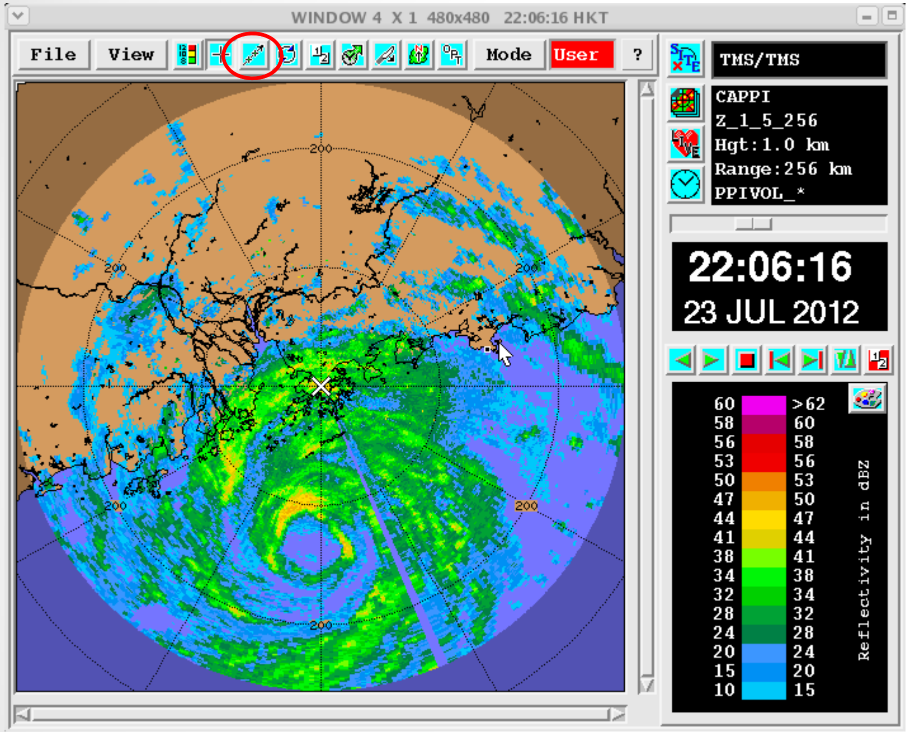


Himawari-8, 02 UTC, 12 Sep 2018

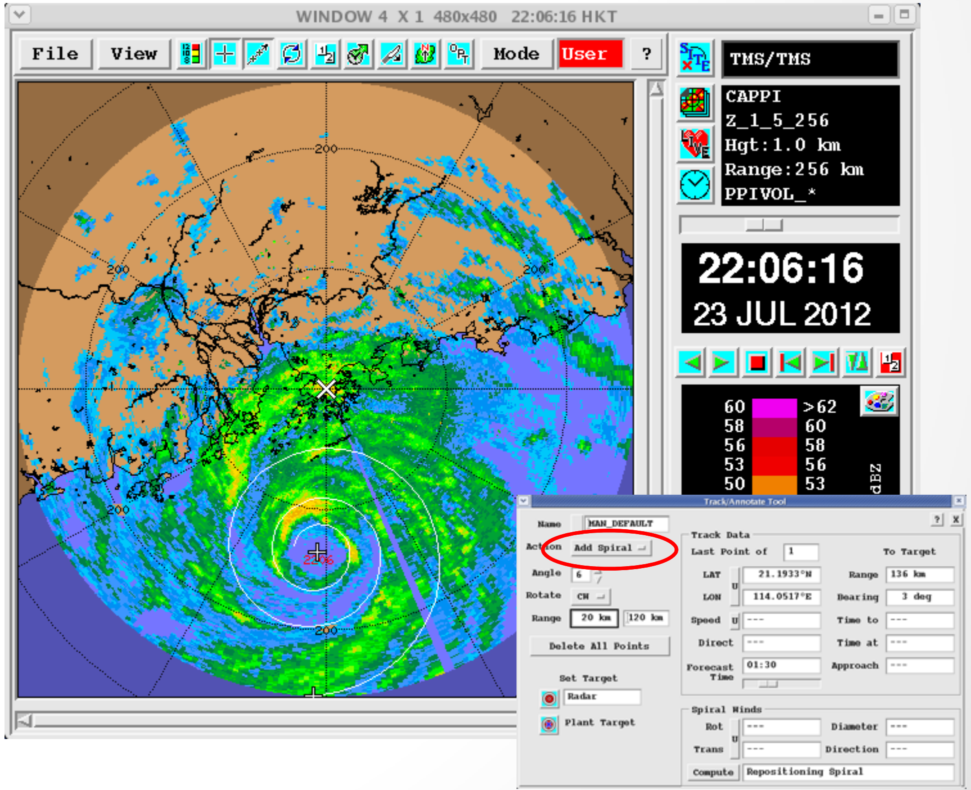




Use of Spiral



Example – Vicente



Example - HAGIBIS

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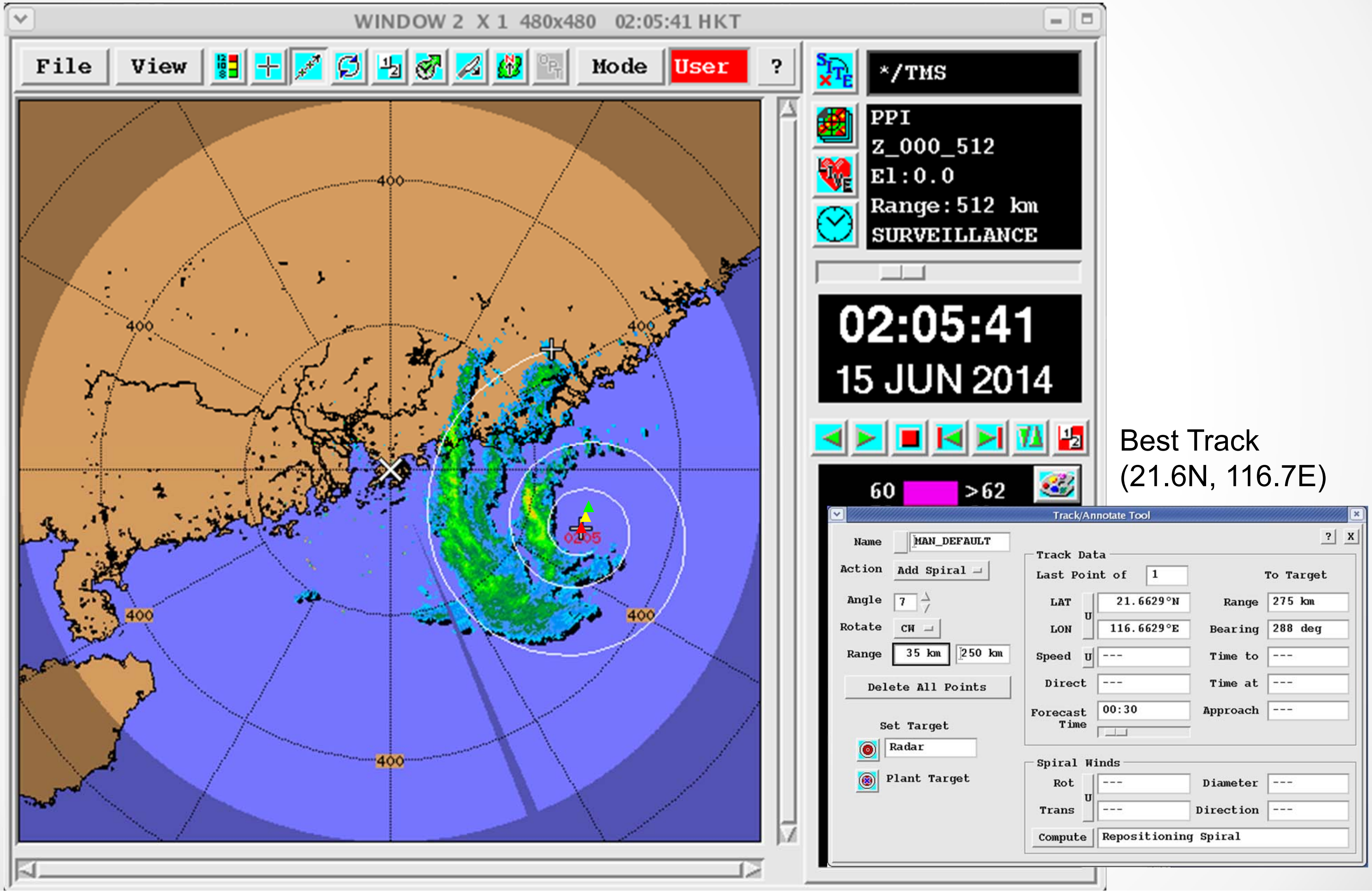
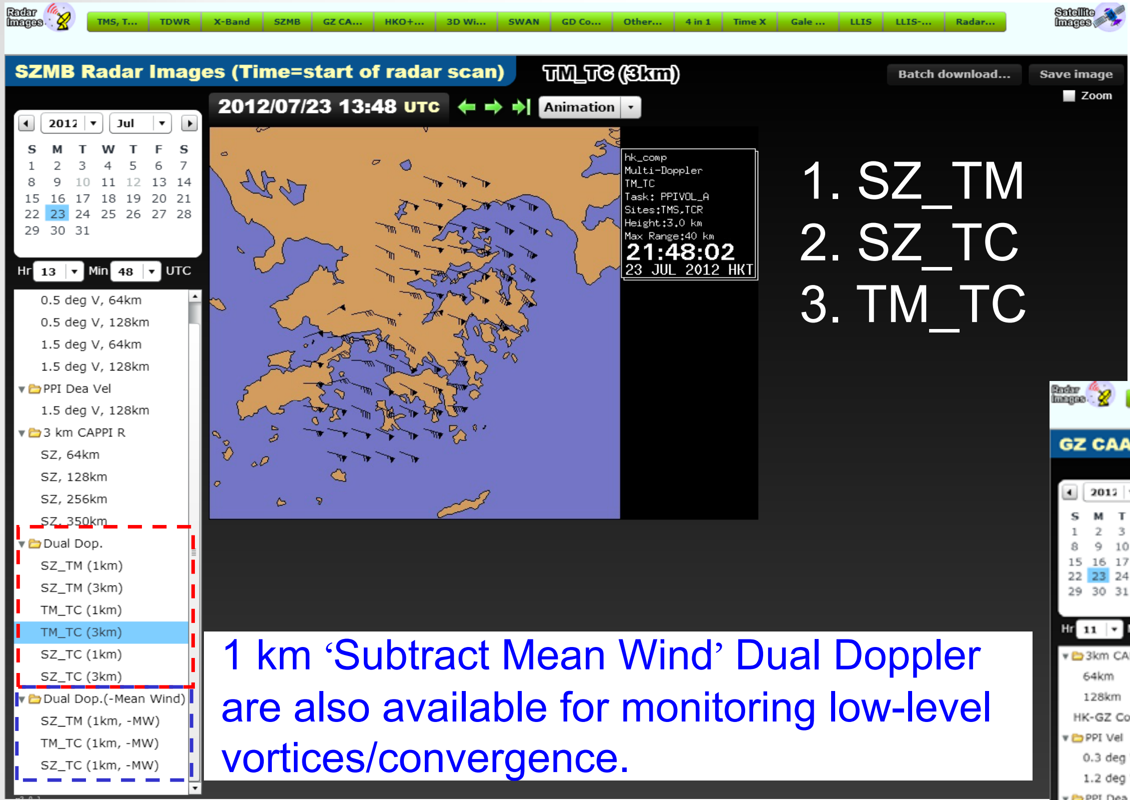


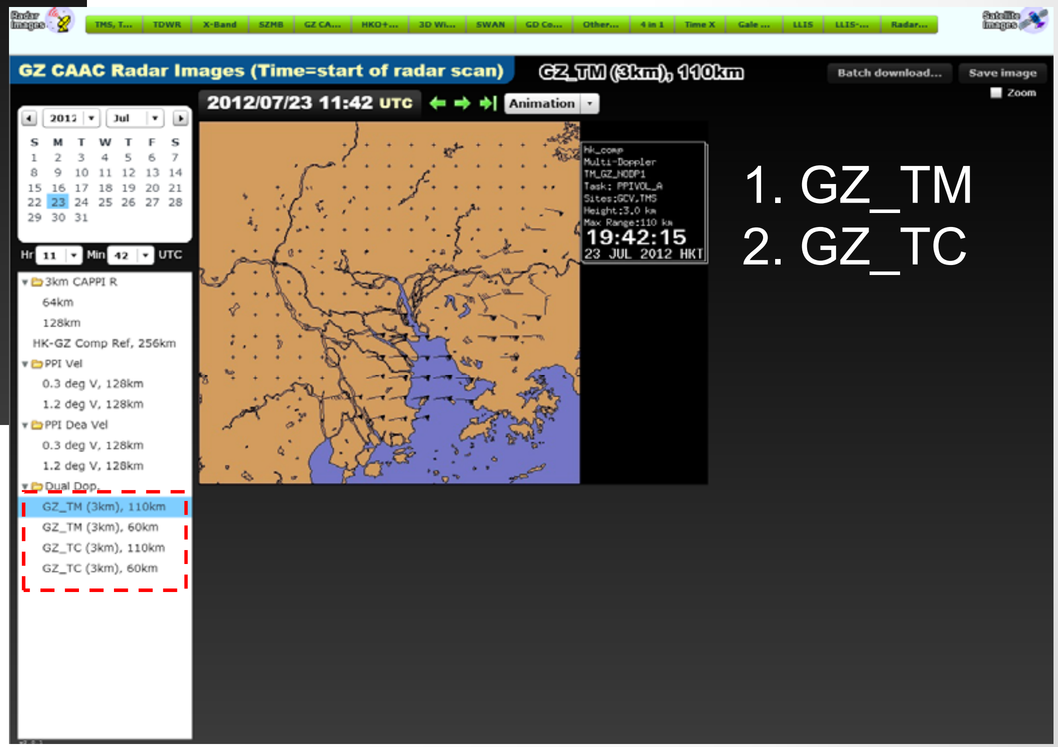
Best Track
(21.6N, 116.7E)

Dual Doppler Wind Products



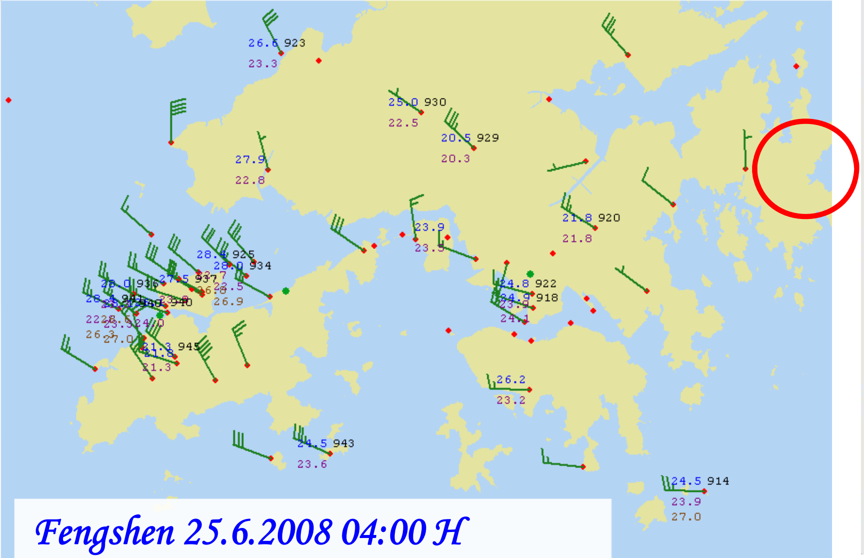
1. SZ_TM
2. SZ_TC
3. TM_TC

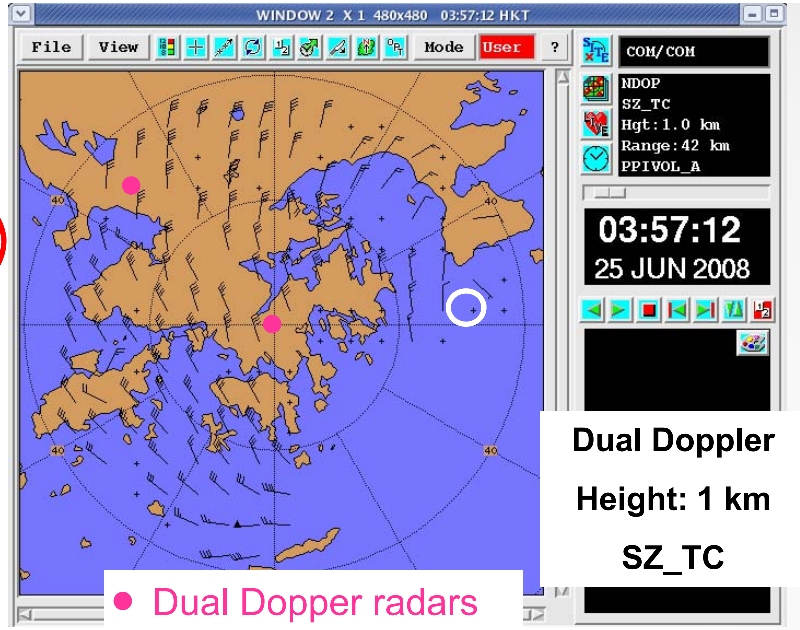
1 km 'Subtract Mean Wind' Dual Doppler are also available for monitoring low-level vortices/convergence.

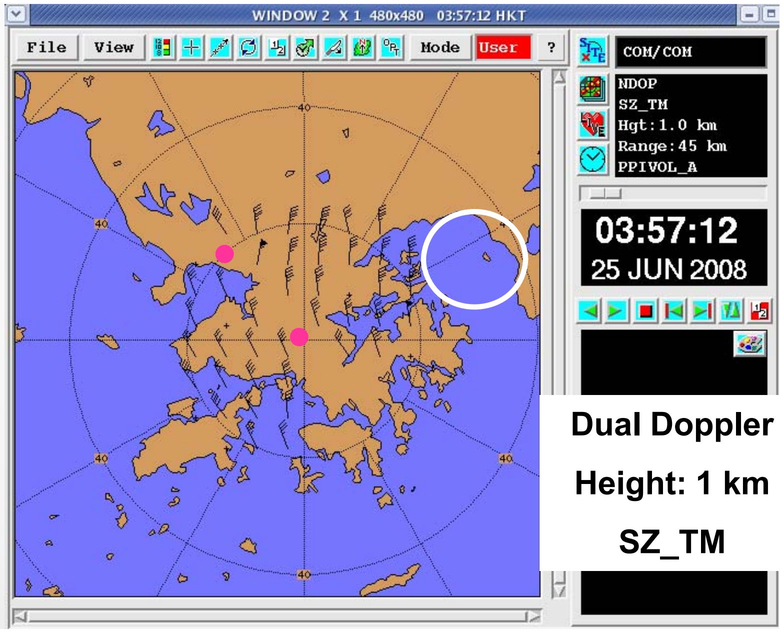


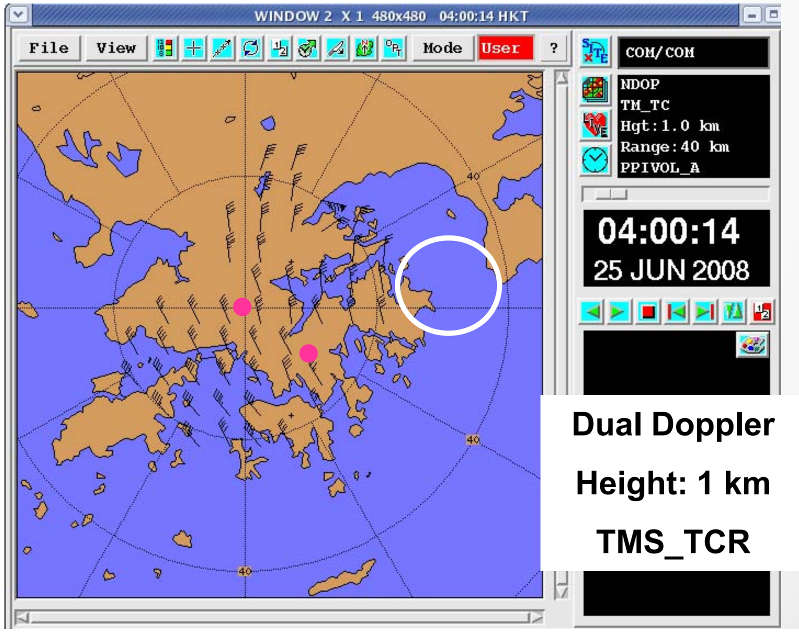
1. GZ_TM
2. GZ_TC

Dual Doppler help locating TC centre



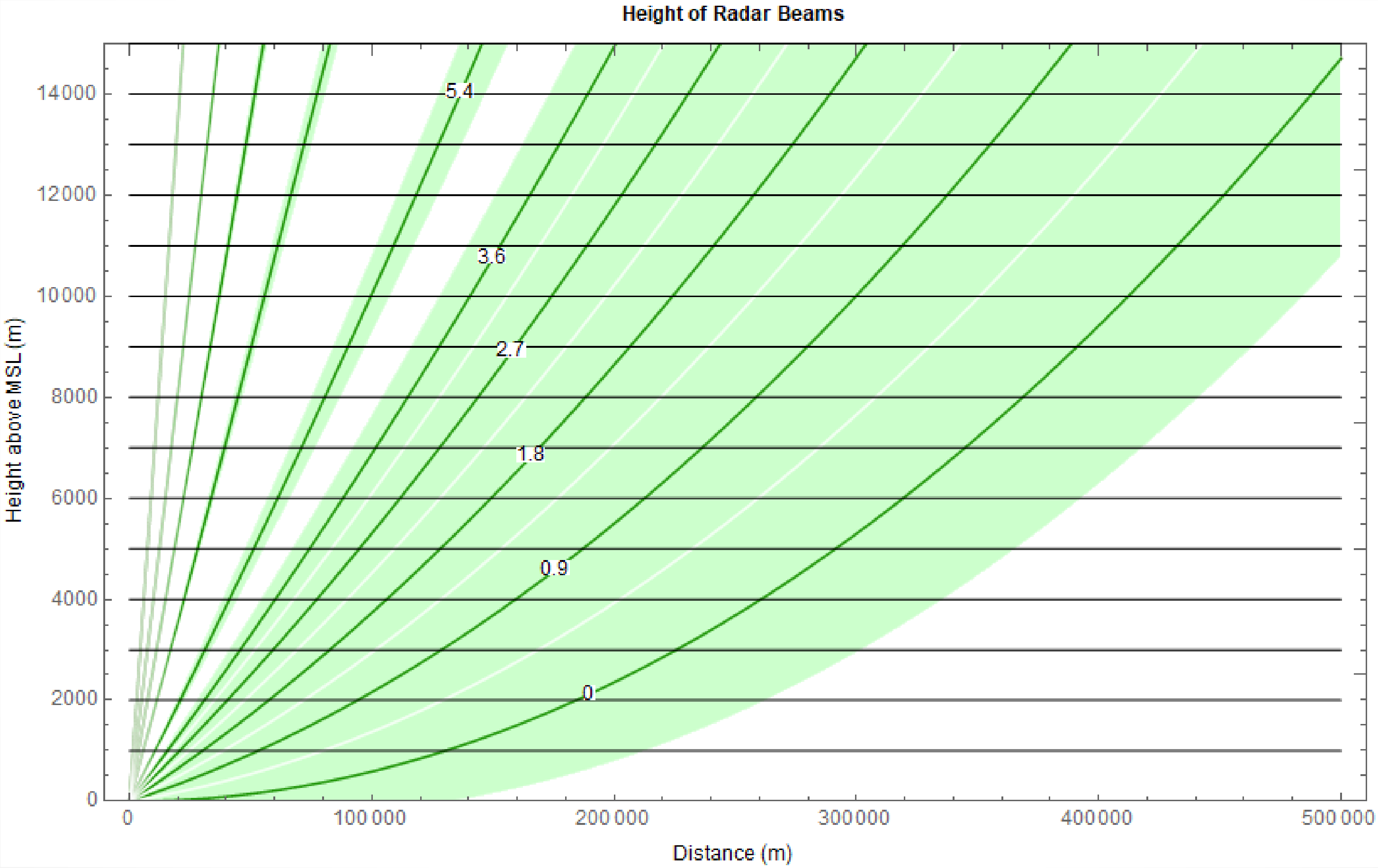




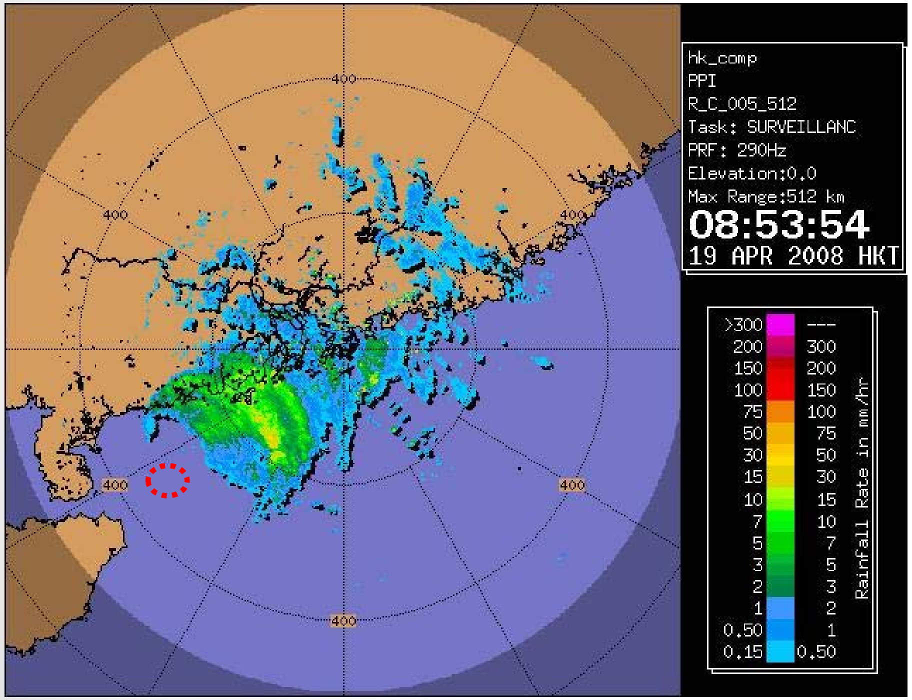


Use of Mosaic Imagery

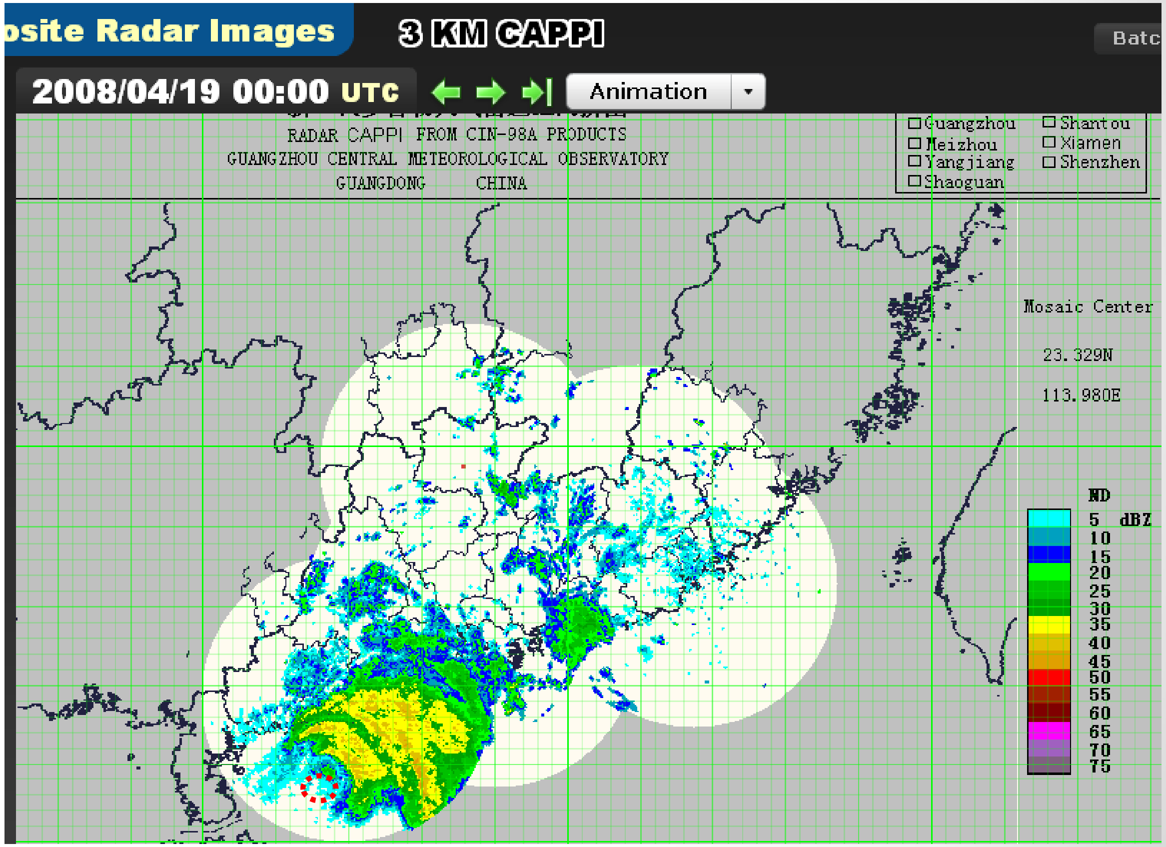
- Radar beam might be too height to capture the low level circulation center of TC.



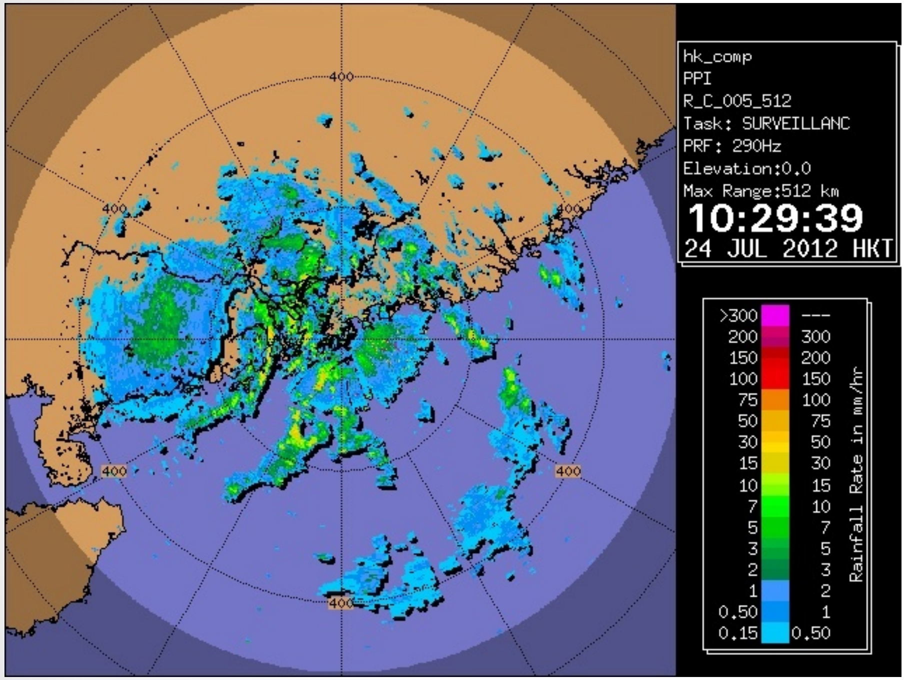
Use of Mosaic Imagery



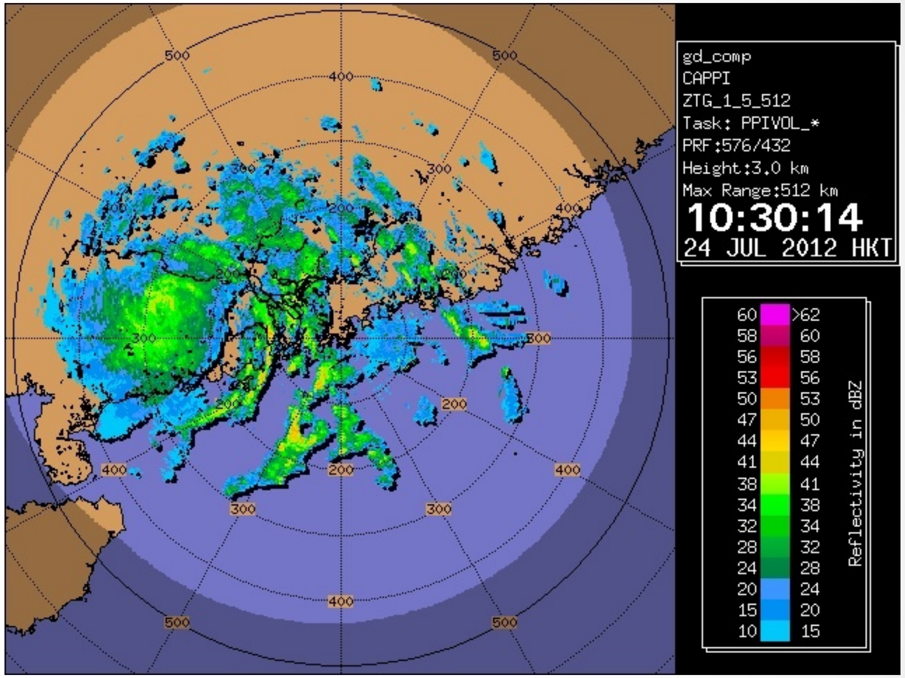
Typhoon Neoguri



Use of Mosaic Imagery



TMS+TCR



GDMB+SZMB+TMS+TCR

- Useful especially when TC has moved to inland

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- Other Considerations in Using Radar

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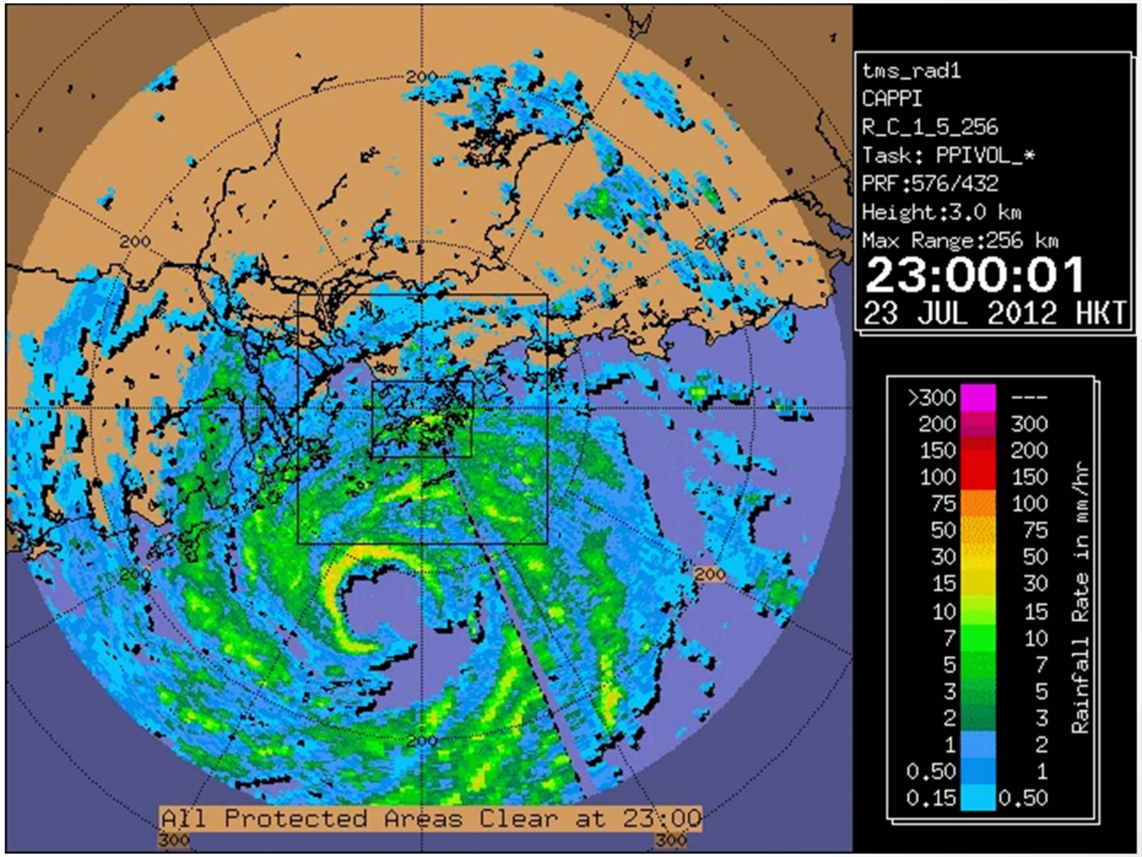
Hot Tower

- Identify hot tower as a signal for rapid development of TC
- Criteria
    1. Echo top > 15 km
    2. Reflectivity > 20 dBZ
    3. Area >=1 sq km



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Estimating Surface winds via Doppler winds aloft

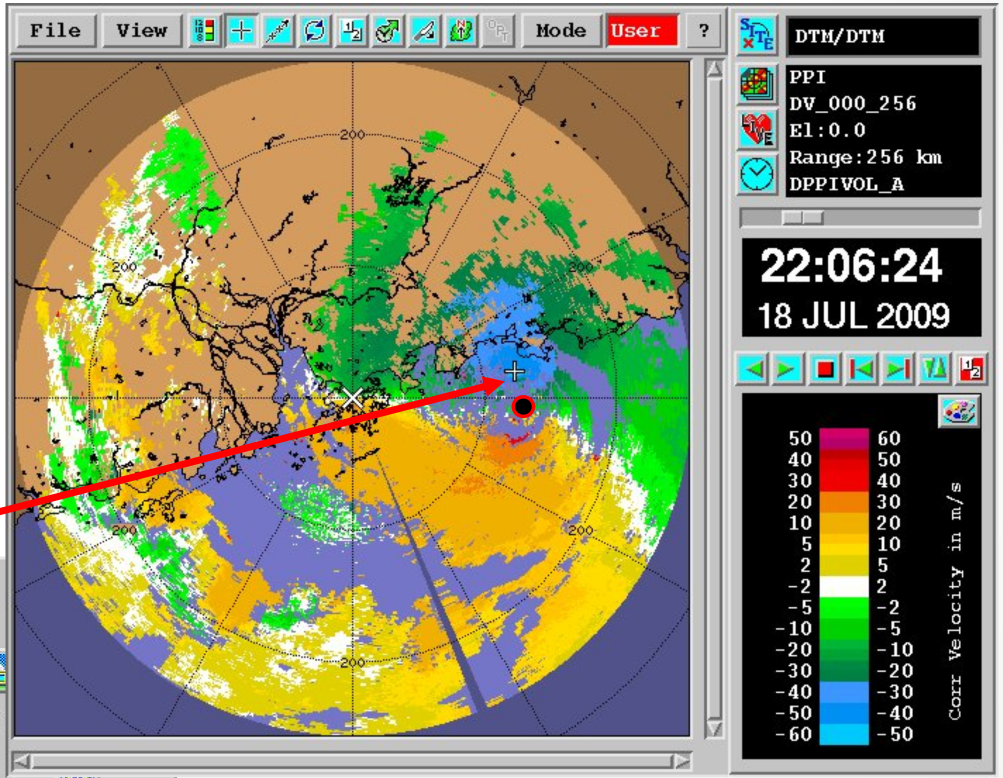
- Forecasters' experience indicated that there is a correlation factor between surface winds and winds aloft during tropical cyclone situations
- Correction factor f = surface wind speed/wind speed at upper-level
- Study result in Hong Kong => f ~ 0.7

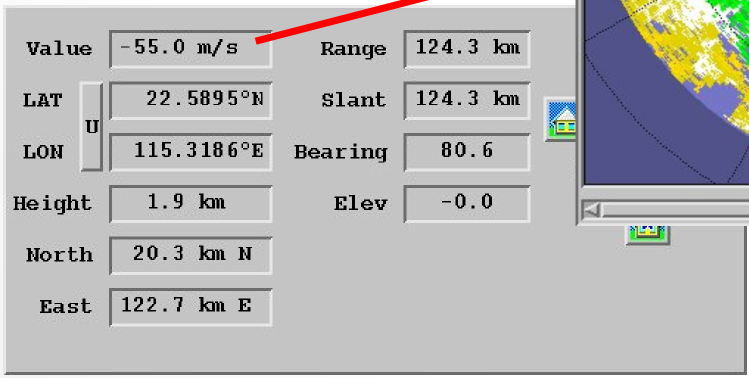
Estimation of central maximum winds of TC

Dealised velocity = -55m/s

Surface equivalent
= 55 m/s x 0.7
= 38.5 m/s (75 kt)

Match pretty close with post - analysis of central max wind 65 kt





● Centre of Molave

Estimation of gale radius of TC

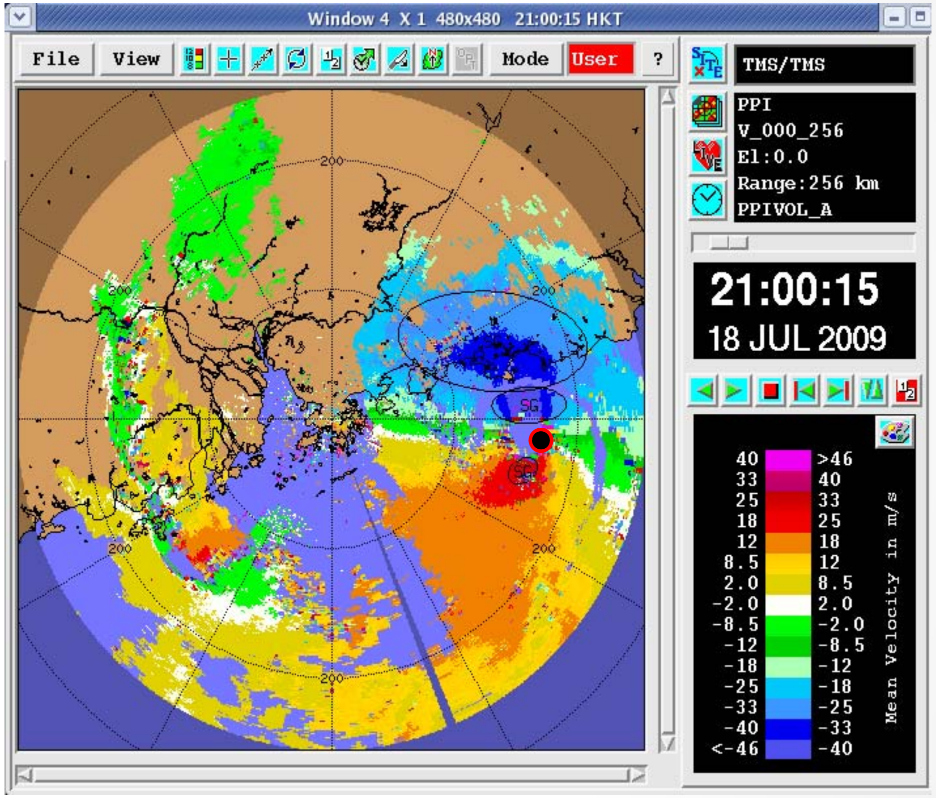
Warning ellipse product SGALE_TMS (Surface Gales) has been configured on TMS 0 deg Doppler velocity PPI (as well as SGALE_TCR on TCR 0.5 deg Doppler velocity PPI).

Surface gale winds = 17.5 m/s

1 km wind speed = 17.5 m/s / f = 17.5 m/s / 0.7 = 25 m/s

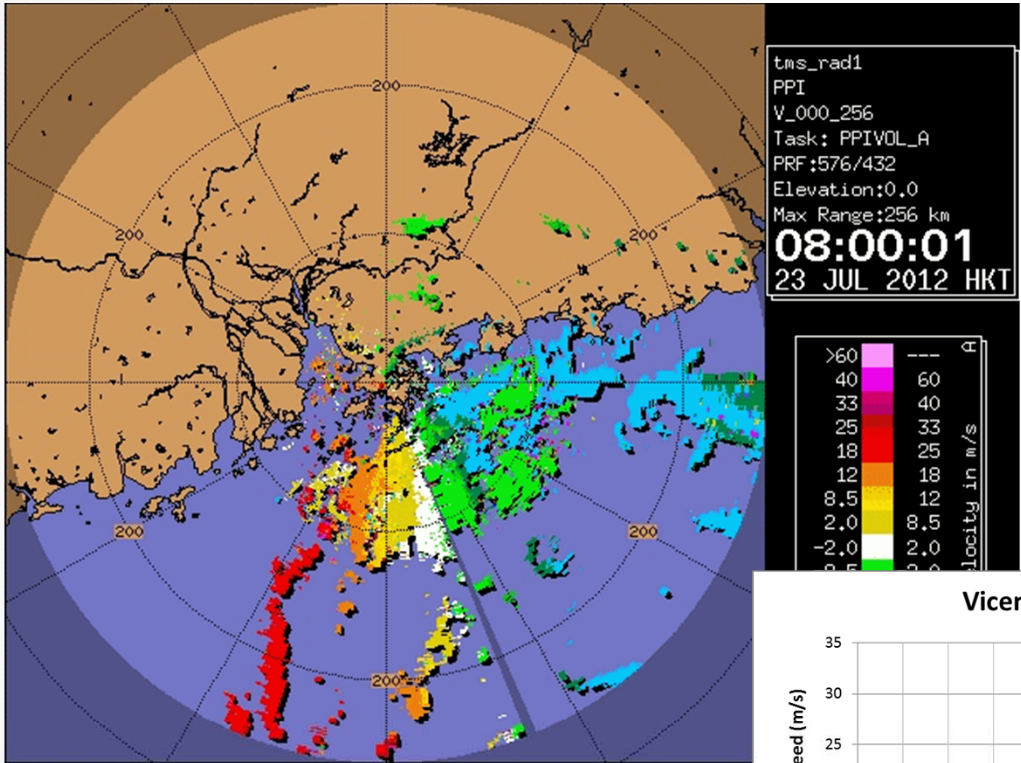
SGALE_TMS (SGALE_TCR) mark ellipses of Doppler winds > 25 m/s, equivalent to surface gales.

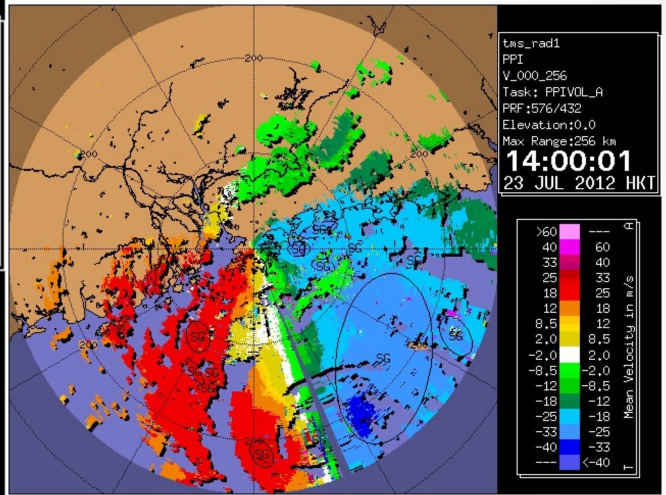
Ellipses with letters 'SG' at centres.

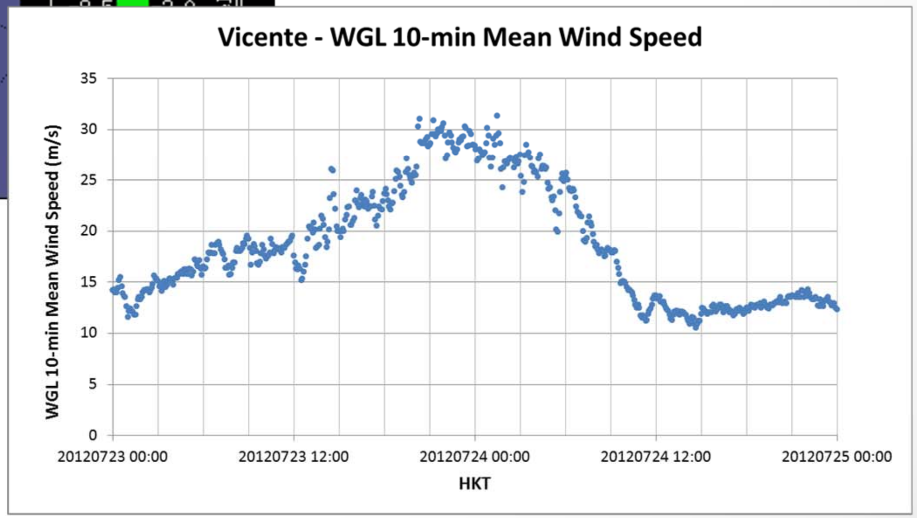


● Centre of Molave

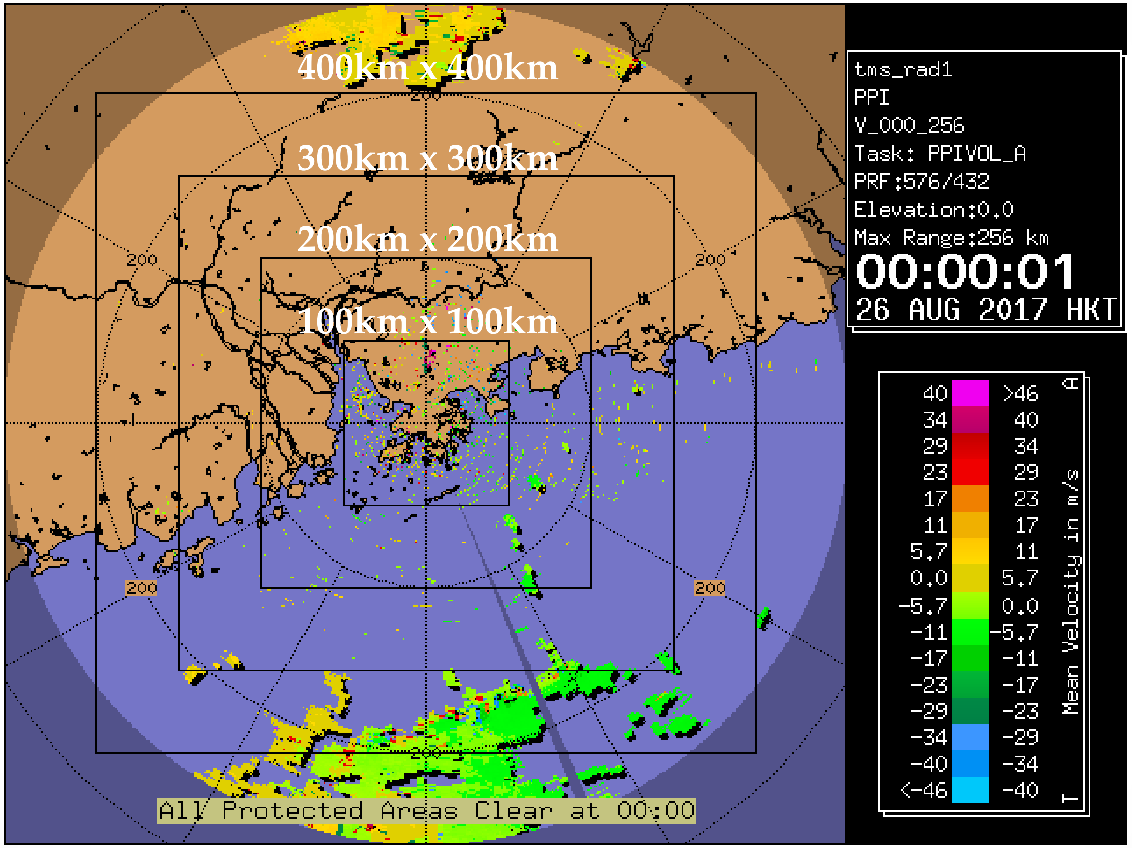
Vicente


tms_rad1
PPI
V_000_256
Task: PPIVOL_A
PRF:576/432
Elevation:0.0
Max Range:256 km
08:00:01
23 JUL 2012 HKT
>60 ---
40 60
33 40
25 33
18 25
12 18
8.5 12
2.0 8.5
-2.0 2.0
200


tms_rad1
PPI
V_000_256
Task: PPIVOL_A
PRF:576/432
Elevation:0.0
Max Range:256 km
14:00:01
23 JUL 2012 HKT
>60 ---
40 60
33 40
25 33
18 25
12 18
8.5 12
2.0 8.5
-2.0 2.0
-8.5 -2.0
-12 -8.5
-18 -12
-25 -18
-33 -25
-40 -33
--- <-40
Mean Velocity in m/s


Vicente - WGL 10-min Mean Wind Speed
WGL 10-min Mean Wind Speed (m/s)
35
30
25
20
15
10
5
0
20120723 00:00
20120723 12:00
20120724 00:00
20120724 12:00
20120725 00:00
HKT

Early Alert of Approaching Surface Gales



PAKHAR 帕卡 (10-min Mean Wind)

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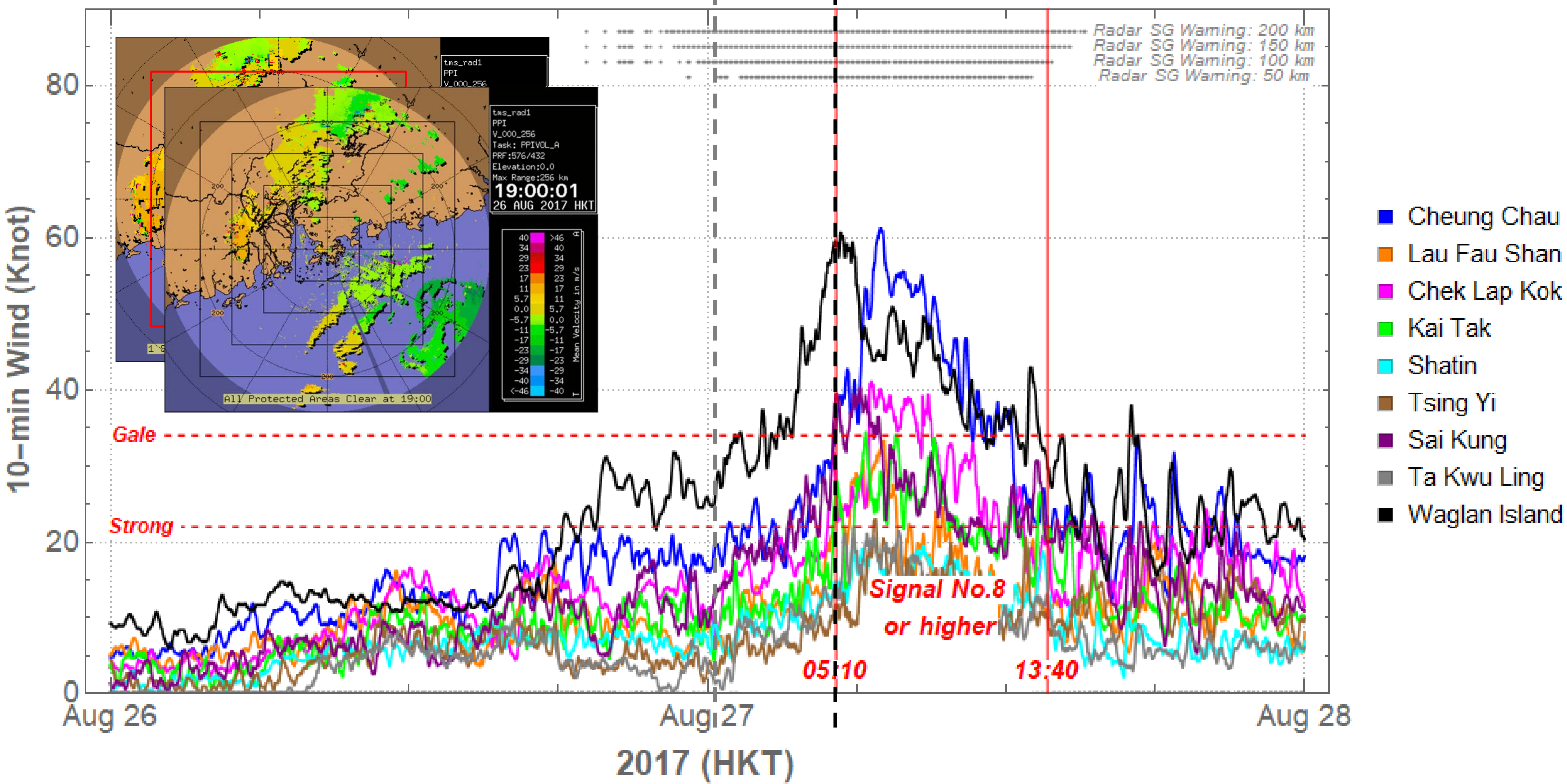

Observation

- 14 cases of TC Warning Signals No. 8 or above from 2011 to 2017
- If radar SG warning (associated with inner and solid rainbands but not (i) outer spiral rainbands or (ii) scattered echoes) appears within 50 km of the territory, gale force winds would start to prevail locally less than 6 hours.

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Background – S-band Radar Rapid Scan Experiment

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- At present, the two S-band long-range radar, namely Tai Mo Shan weather radar (TMSWR) and Tate's Cairn weather radar (TCWR), adopt a 6-minute volume scan with 10 elevations from 0° to 34°.
- The two radars operate in tandem to provide redundancy in radar services to internal and external users.
- To enhance radar observations, an experiment on TMSWR rapid scan commenced in 2017.
- Scanning strategy: 1 min 1 slice at 0°
- Higher elevations data would be complemented by TCWR volume scan.
- Apparent benefits to weather monitoring

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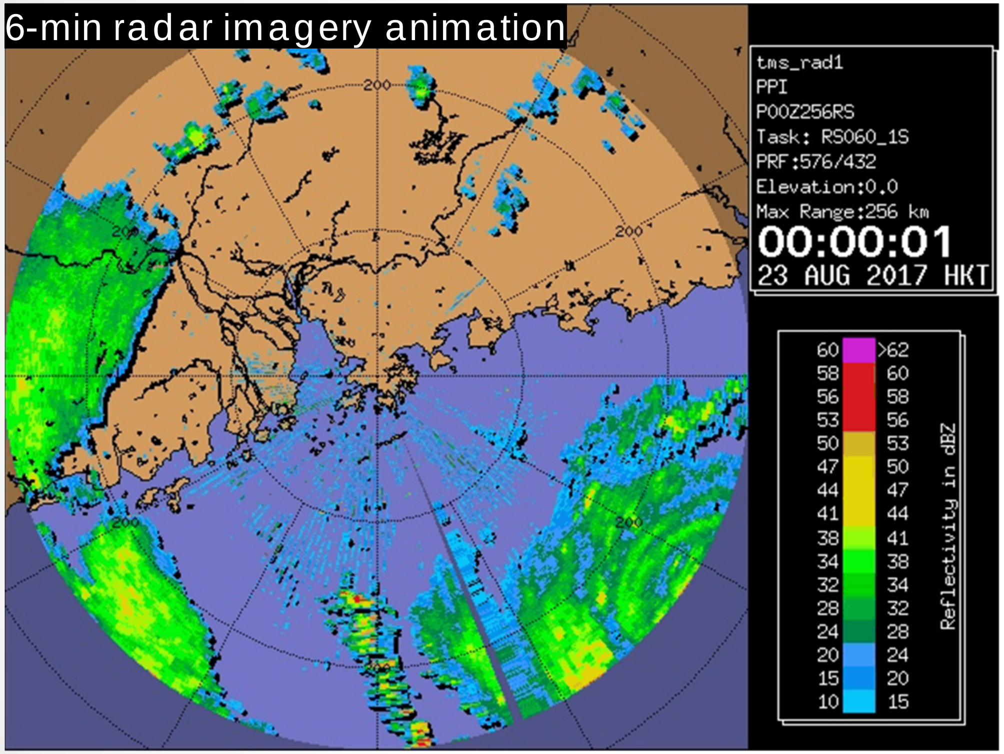
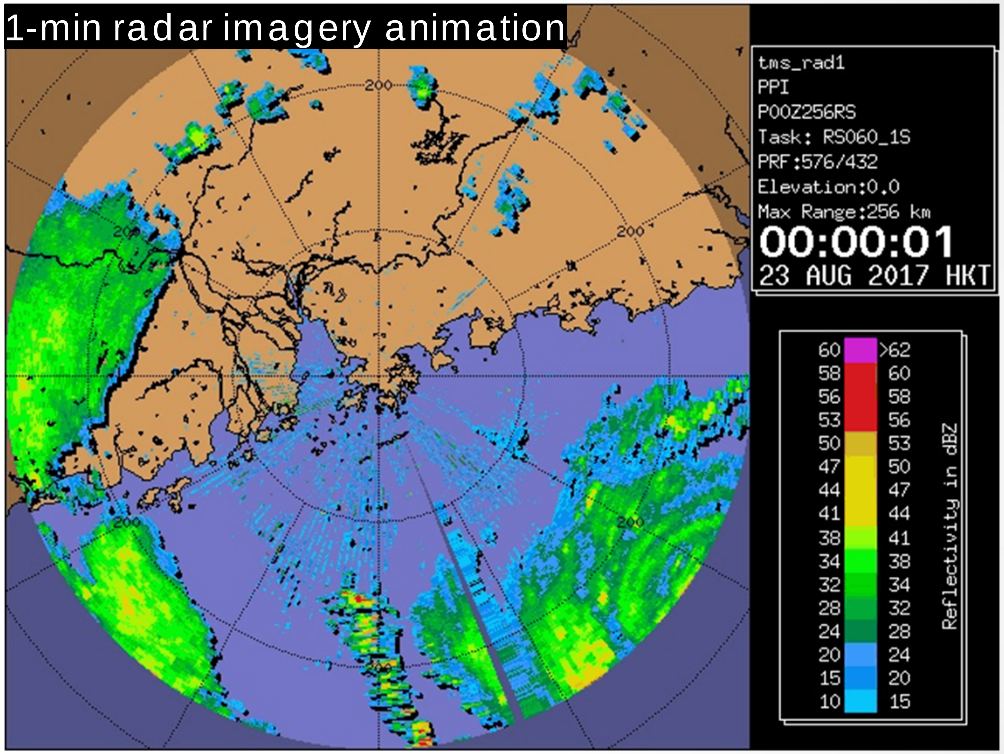
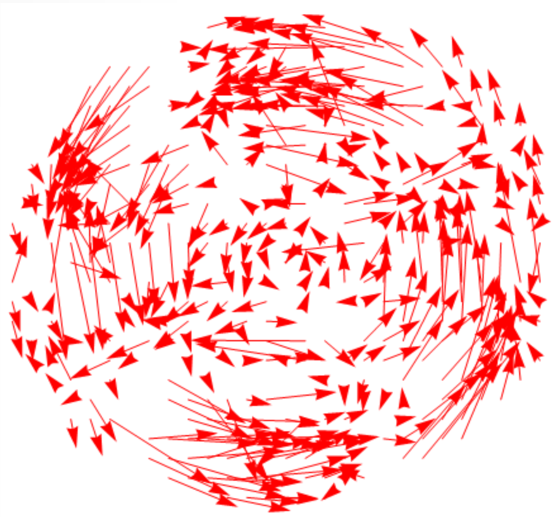
Enhanced observations – Estimation of tropical cyclone intensity



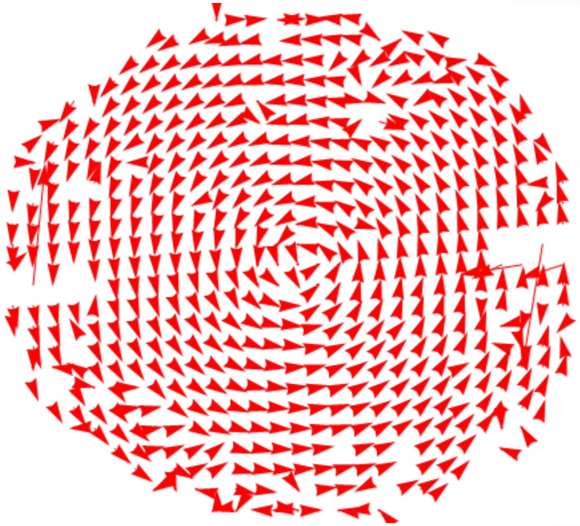


- TC Hato intensified rapidly into a Super Typhoon when moving towards the coast of Guangdong on 23 August 2017.
- 1-min radar animation shows clearly (i) contraction of TC eye and (ii) increase of angular speed.

Motion vector fields derived by pattern recognition techniques



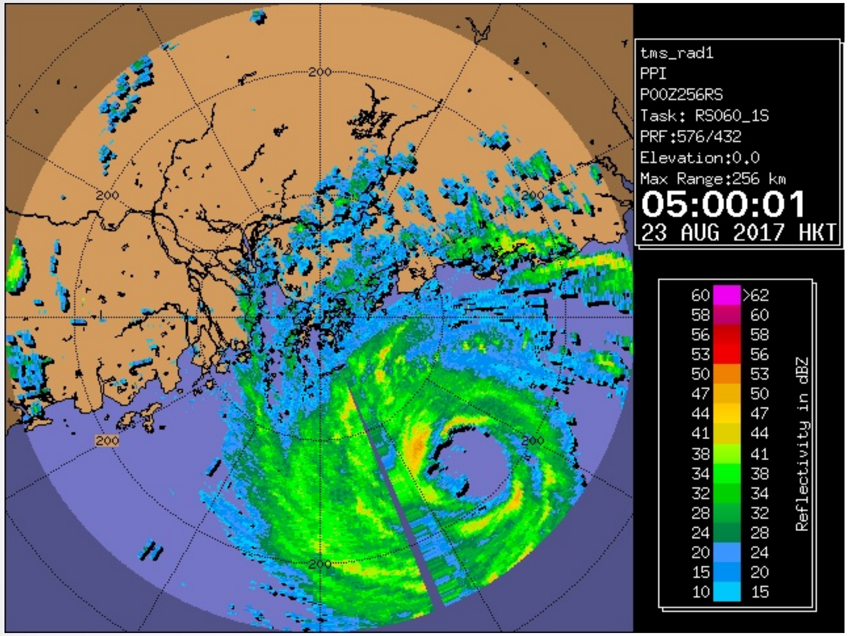
MVF derived using two successive simulated 6-minute volume scan data

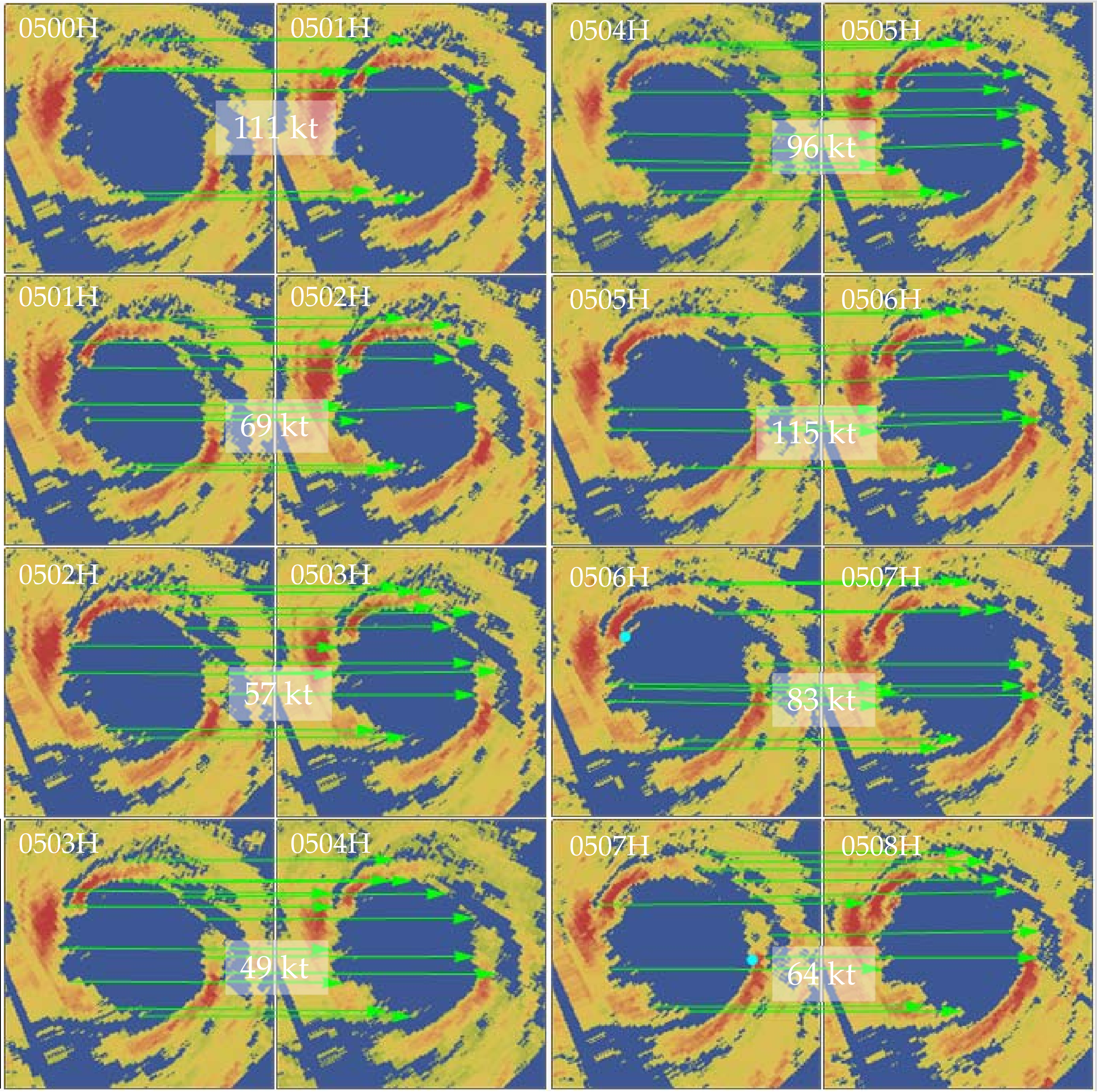


MVF derived using two successive simulated 1-minute rapid scan data

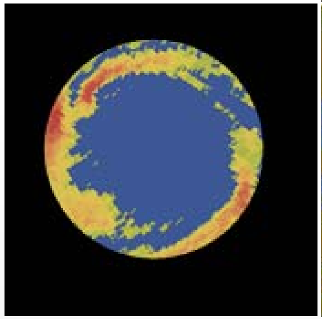
- Better MVF using 1-minute rapid scan data.
- Suggest possibility to estimate the rotation speed of radar echoes near the eye wall.
- Time-lag ensemble approach to average out the short-term fluctuation.

Feature Tracking

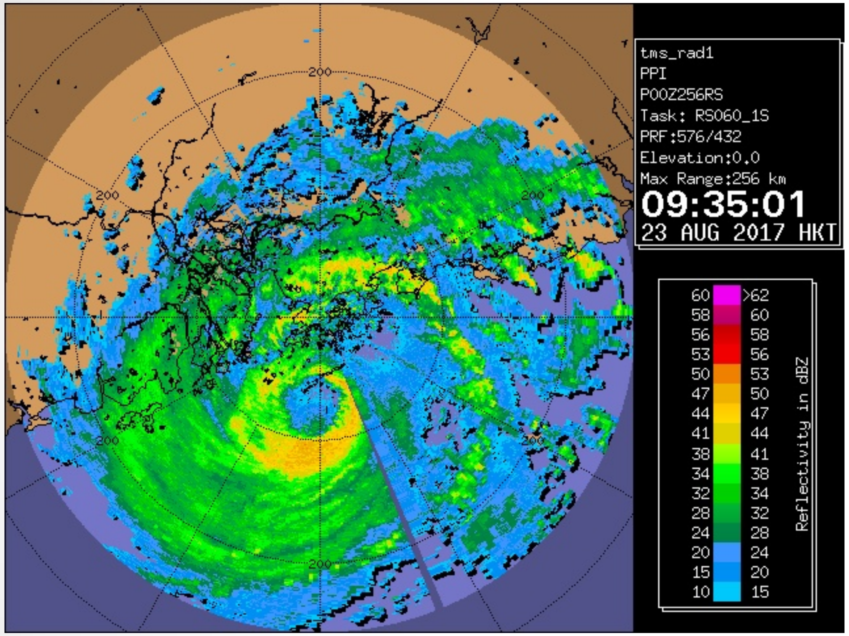




Average speed near eye wall = 80 kt

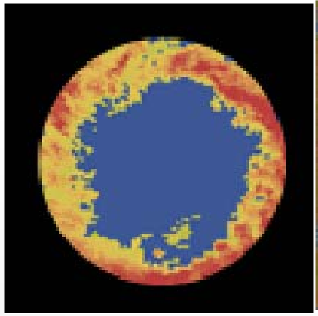


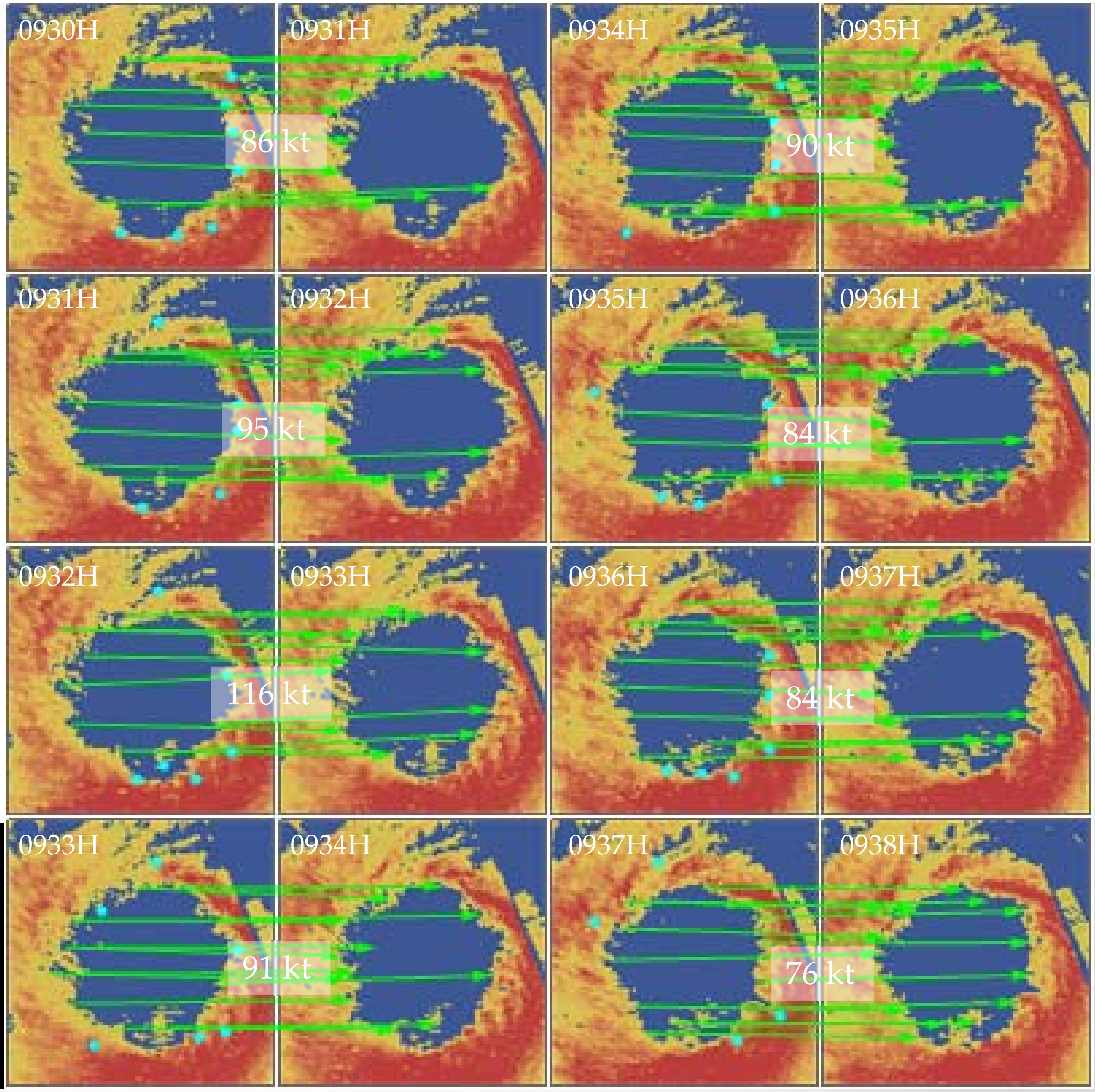
Feature Tracking



Average speed near eye wall = 90 kt

V_{eye} increased by 13%





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Comparison with the HKO Best Track of TC Hato

	Maximum Wind Speed from HKO Best Track data	TC feature tracking method
0500 HKT, 23 Aug 2017	80 knots	80 knots (average speed based on 0500-0508 HKT 1-minute rapid scan radar imageries)
0930 HKT, 23 Aug 2017	97.5 knots	90 knots (average speed based on 0930-0938 HKT 1-minute rapid scan radar imageries)
Percentage of Intensity Change	+22%	13%

- More TC cases would be required to verify if the average moving speeds of echo features near the TC centre found by feature tracking method could well represent the maximum wind speed near the centre of a TC.
- The feature tracking method seems to provide a good reference in estimating the TC maximum wind speed and its intensity change.

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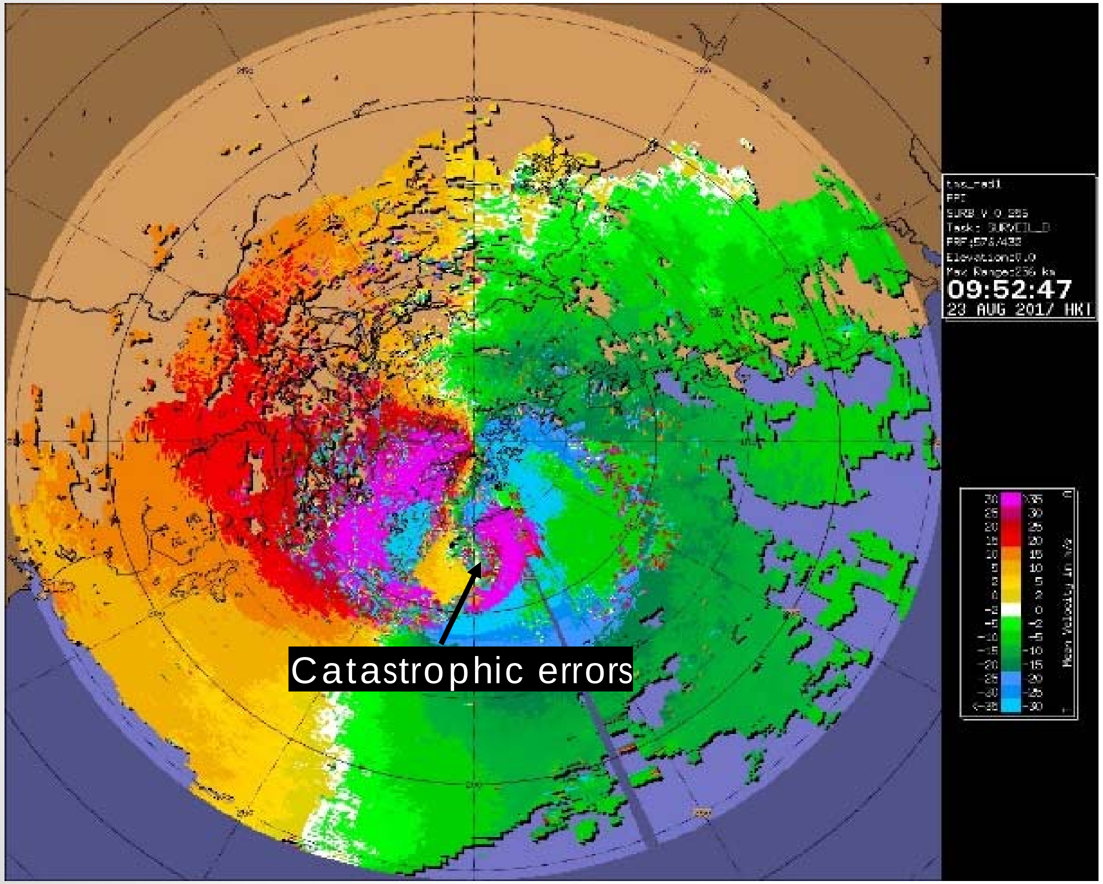
Catastrophic errors near eye wall



- Usually more catastrophic errors near the eye wall of TC.
- Increases the difficulty to estimate TC intensity using Doppler velocity information directly.
- The feature tracking method requires only radar reflectivity imageries, and provides another diagnostic method to estimate TC intensity even when the catastrophic errors are significant

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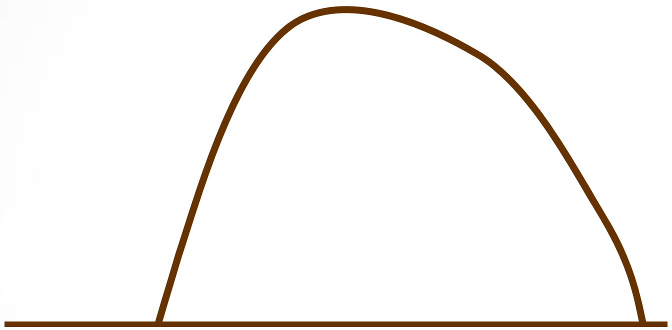
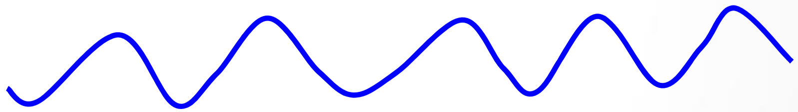
Weather Monitoring by Radar

Clutters

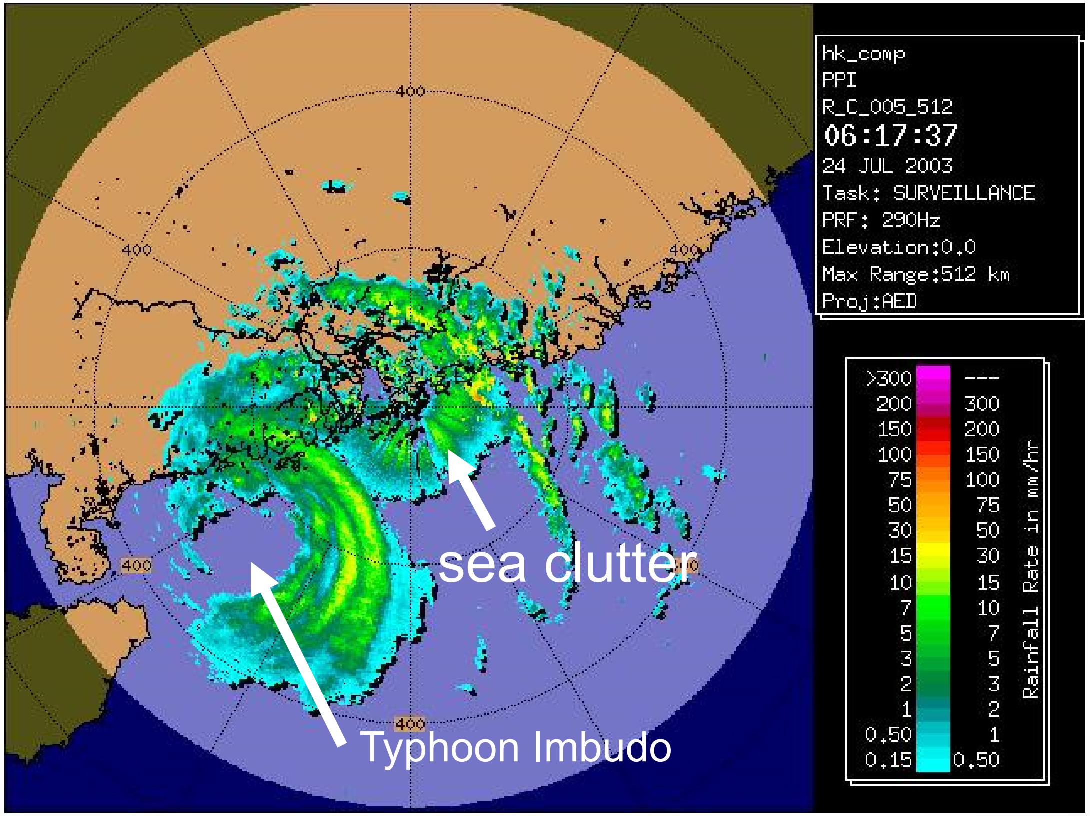


Land Clutter – mountains, buildings, ships, aircraft, birds, tree leaves, etc



Sea Clutter – waves

Sea Clutters 海面杂波



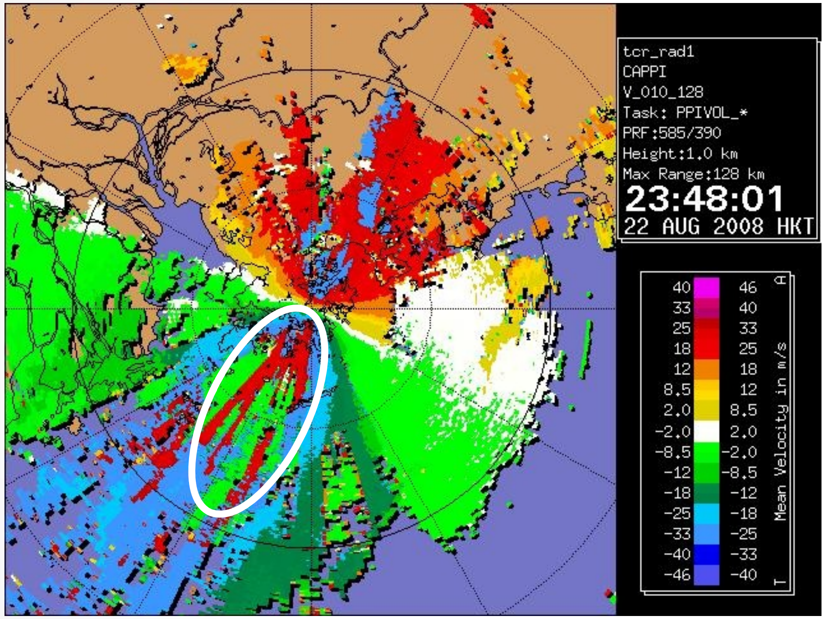
Doppler dilemma

$$D_{\max} = \frac{c\,\Delta T}{2} \qquad v_{\max} = \frac{\lambda}{4\,\Delta T}$$

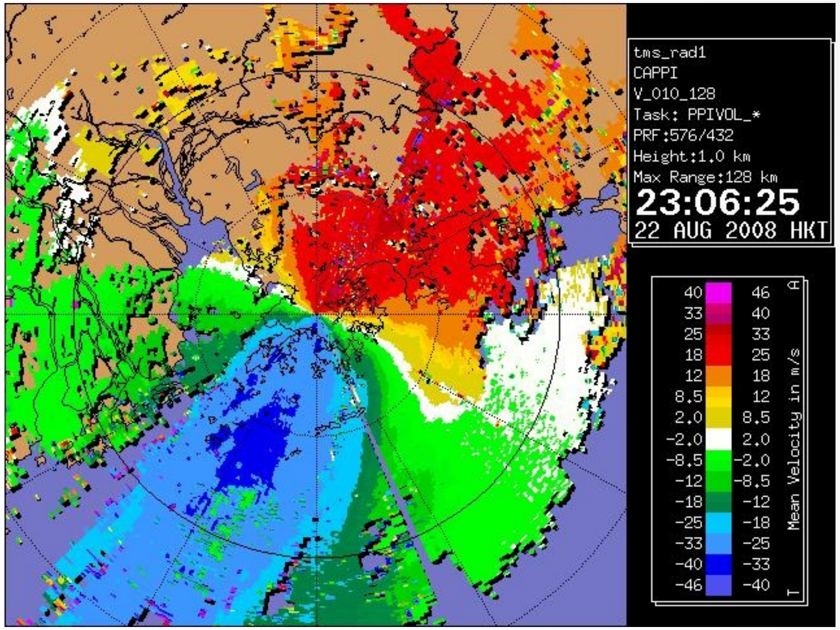
$$D_{max} v_{max} = \frac{c\lambda}{8}$$

- Increasing ΔT will increase $D_{\max}$ at the expense of $v_{\max}$
- If we choose a low PRF (high ΔT) to increase the range, the Nyquist will be small.
- If we choose a high PRF (low ΔT) to increase the Nyquist, the range detected will be small.

Velocity Folding



Velocity folding (white ellipse)
(Nyquist velocity = 30 m/s)



No Velocity folding
(Nyquist velocity = 45.9 m/s)

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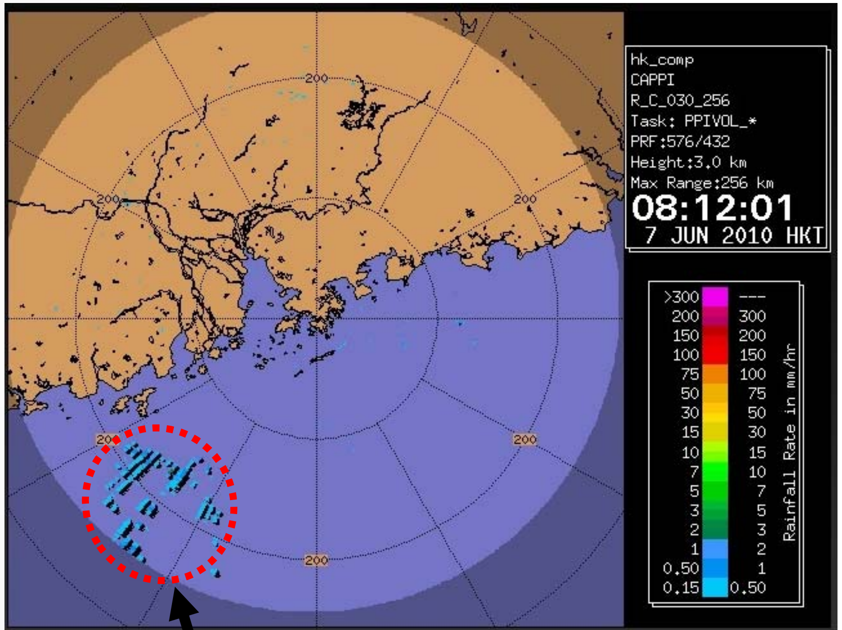
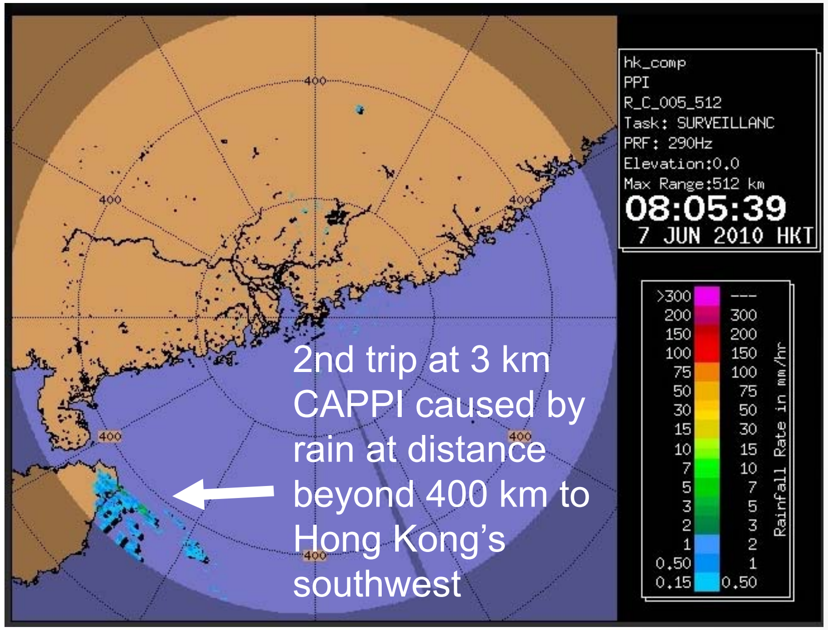
Range Folding – Second Trip Echoes

3 km CAPPI at 256 km range



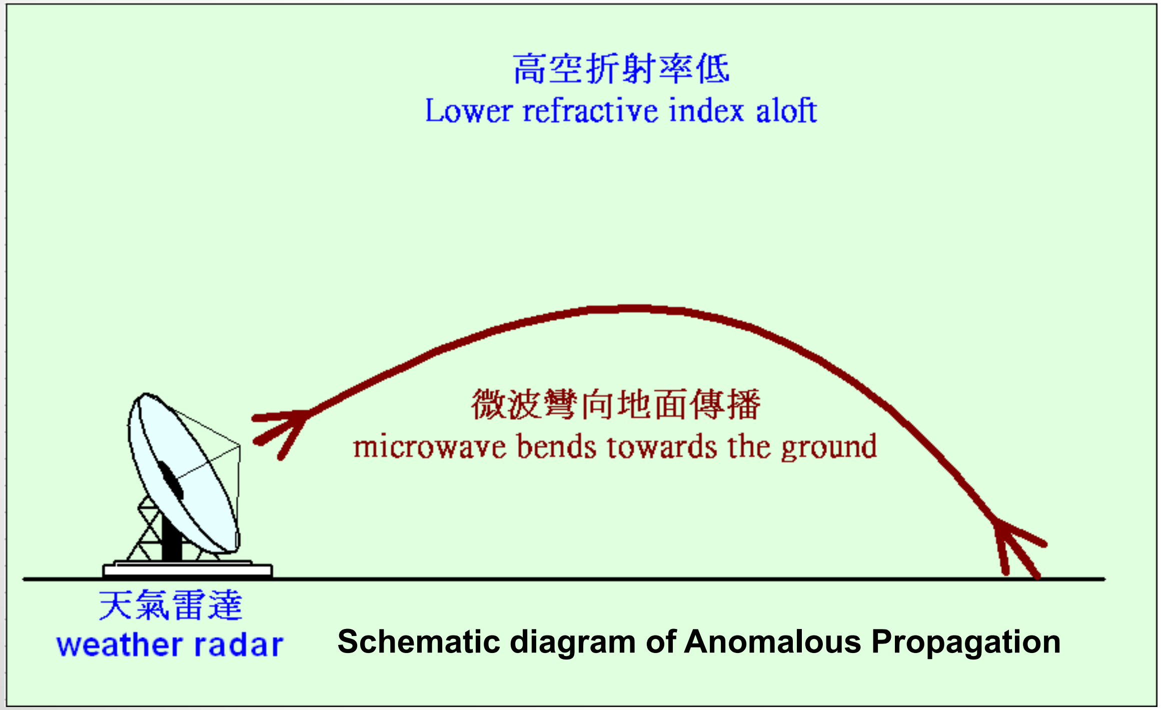
0.0 deg TMS PPI at 512 km range



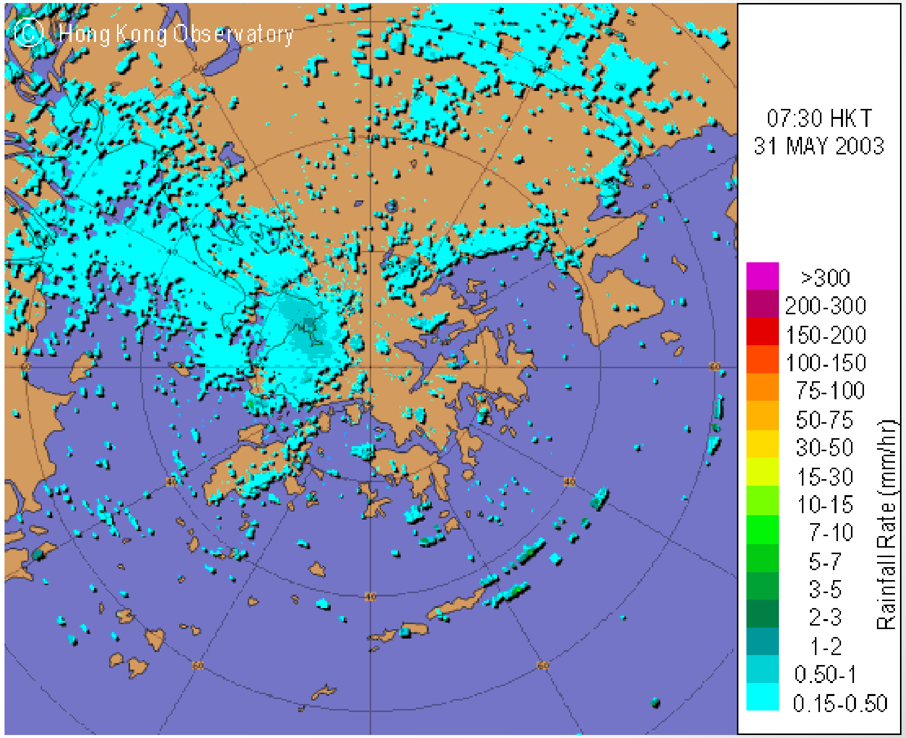
'Second Trip Echoes' in the form of strips (because of alternate PRF) were caused by rain at a distance beyond 400 kilometres to southwest of the radar.

Anomalous Propagation

When the air is stable, the microwave from radar which would otherwise travel in a straight line might bend towards the ground (like mirage). The reflected microwave would give the radar a false impression of rain. Usually lots of ‘anaprop’ on radar picture means dry and stable weather!



Schematic diagram of Anomalous Propagation



Q&A