

Latest Developments of Numerical Weather Prediction at HKO

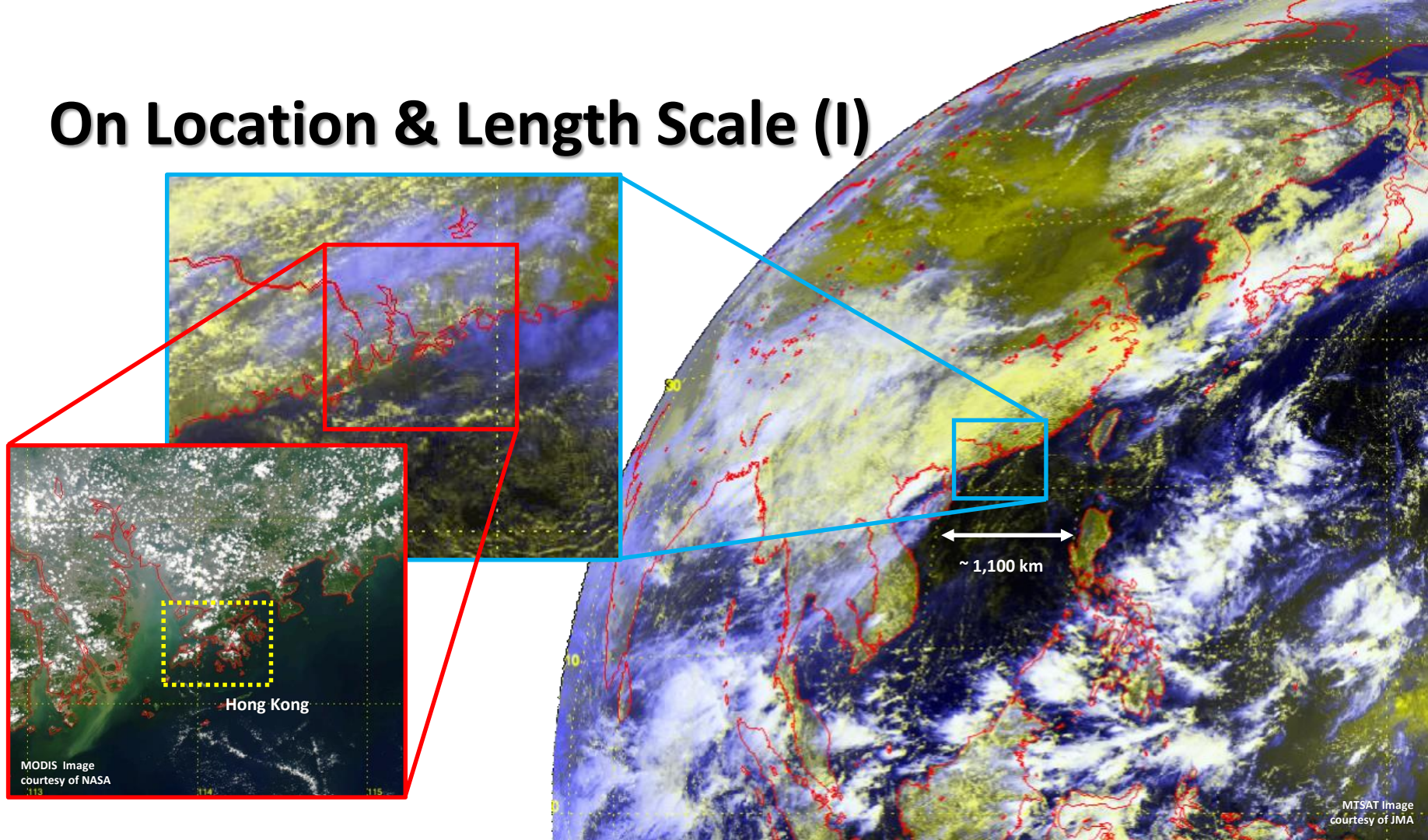
WMO VCP Workshop

8th December 2020, Hong Kong, China

KK Hon

Acting Senior Scientific Officer

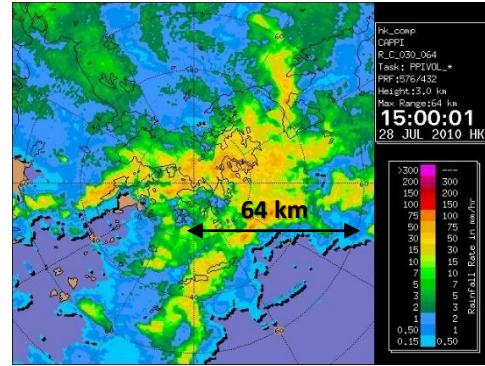
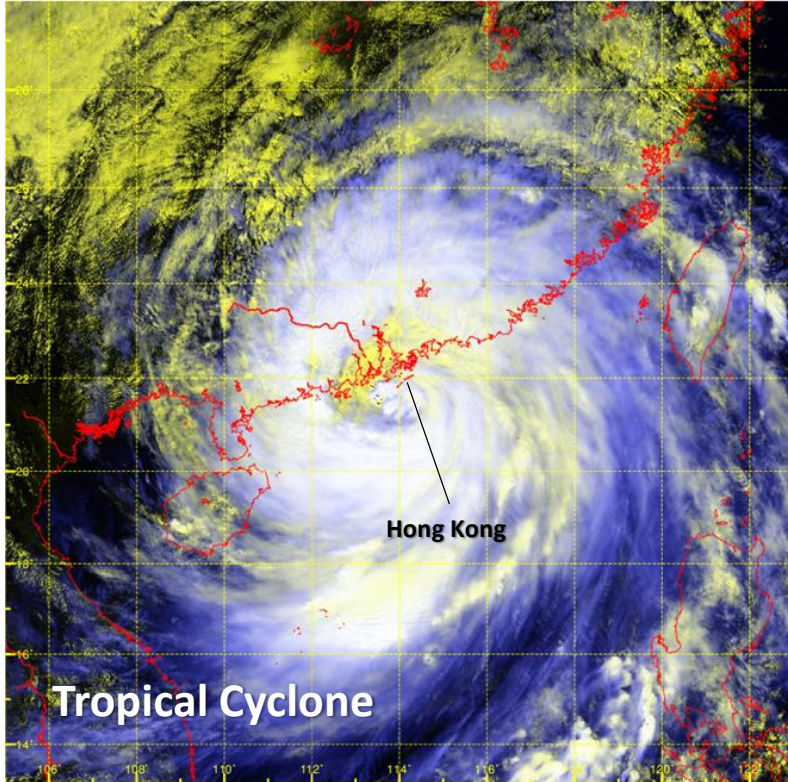
On Location & Length Scale (I)



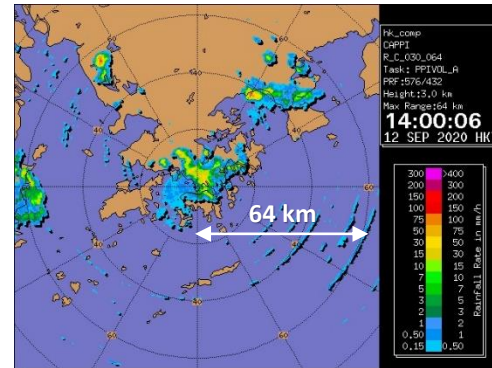
MODIS Image
courtesy of NASA

MTSAT Image
courtesy of JMA

On Location & Length Scale (II)



Localised Heavy Rain



Synoptic

Meso-

Storm-

Micro-Scale

High-Performance Computing (HPC) Systems



AVM-HPC (2013)
20 TFLOPS
At HK Int'l Airport

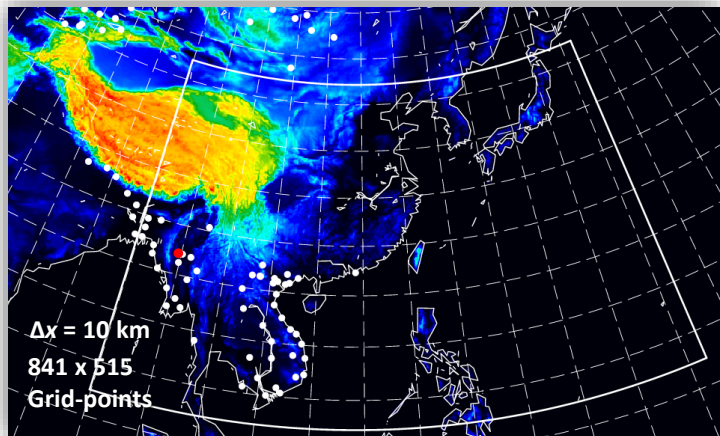


eNICE/NICE (2014)
Total 26 TFLOPS
Installed at HKO HQ L/G



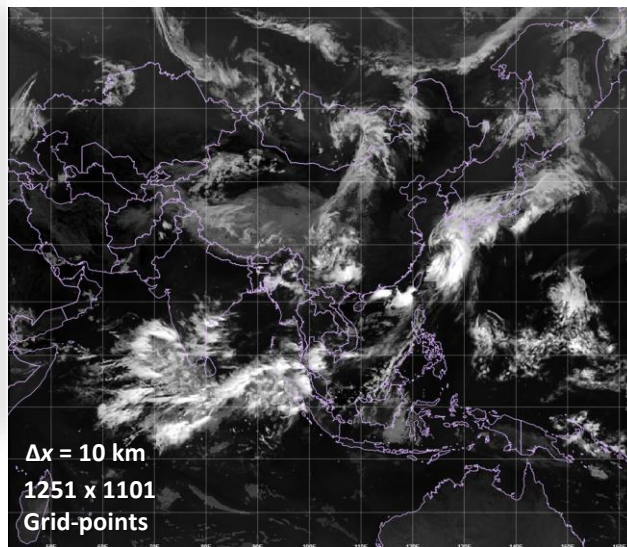
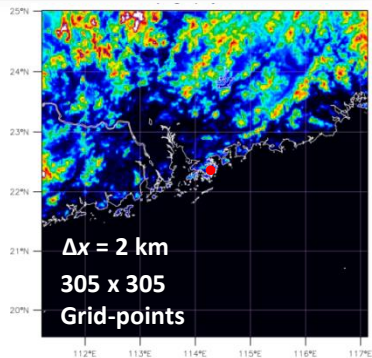
NICER (2019)
200 TFLOPS
NICE-Replacement

Deterministic Meso-/Fine-scale NWP



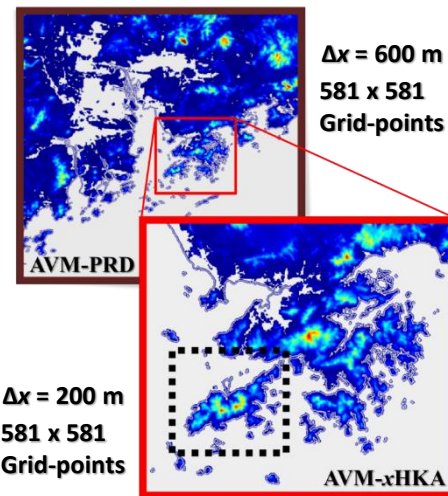
**Meso-NHM &
Rapids-NHM**

(based on JMA-
NHM)



**AAMC-WRF
(Experimental)**

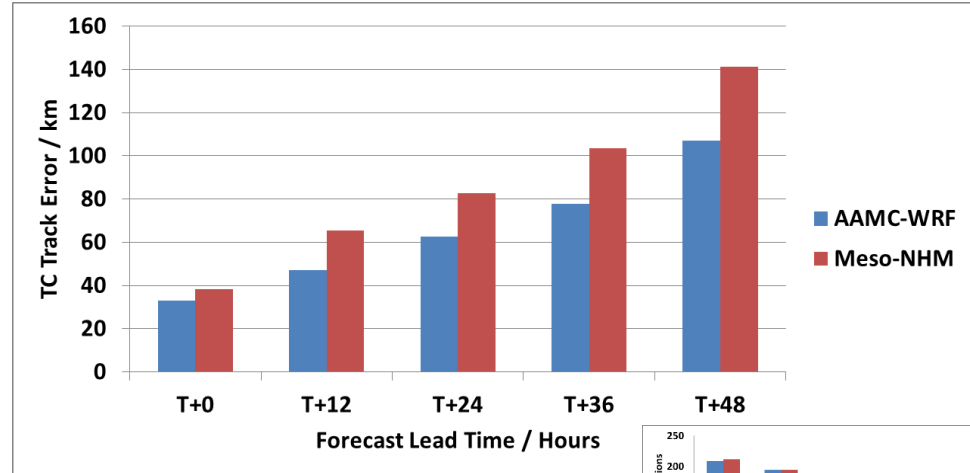
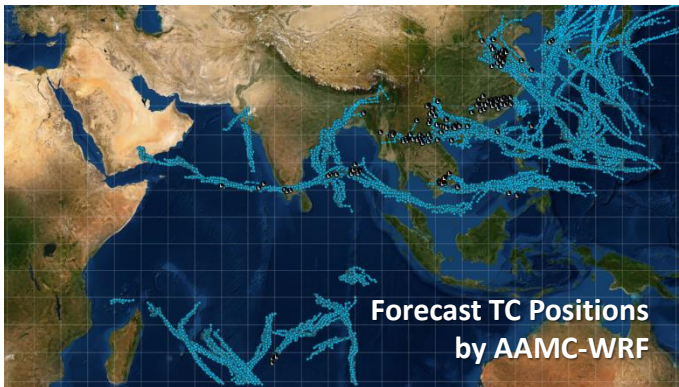
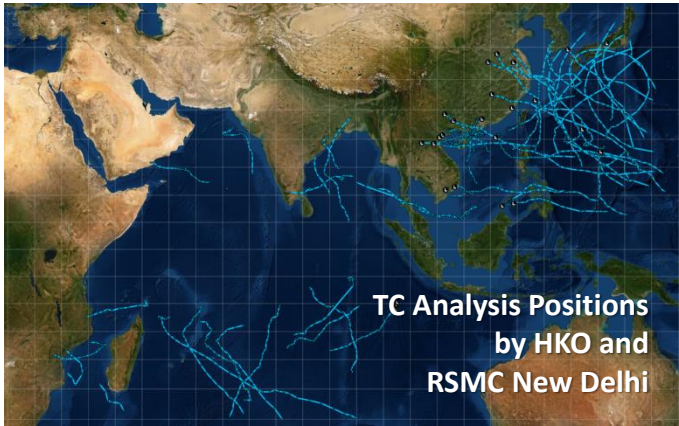
(based on WRF-ARW)



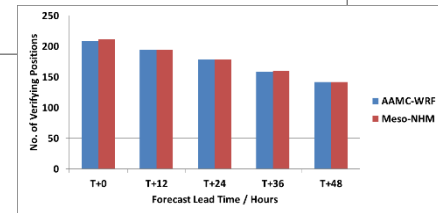
**AVM-PRD &
AVM-xHKA**

(based on WRF-ARW)

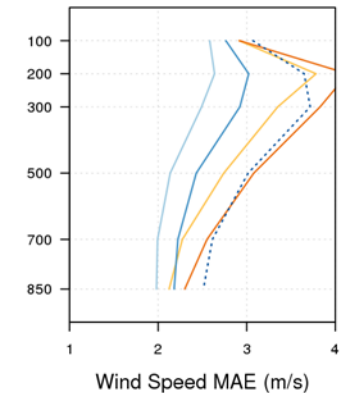
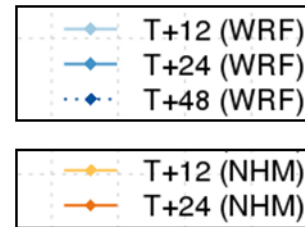
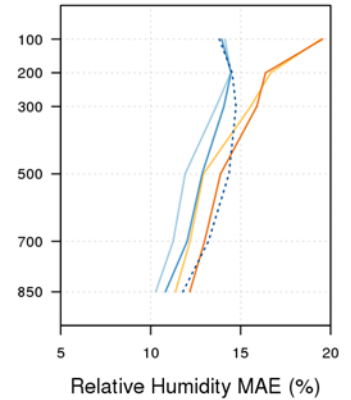
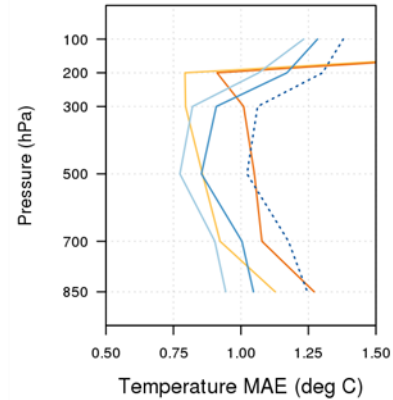
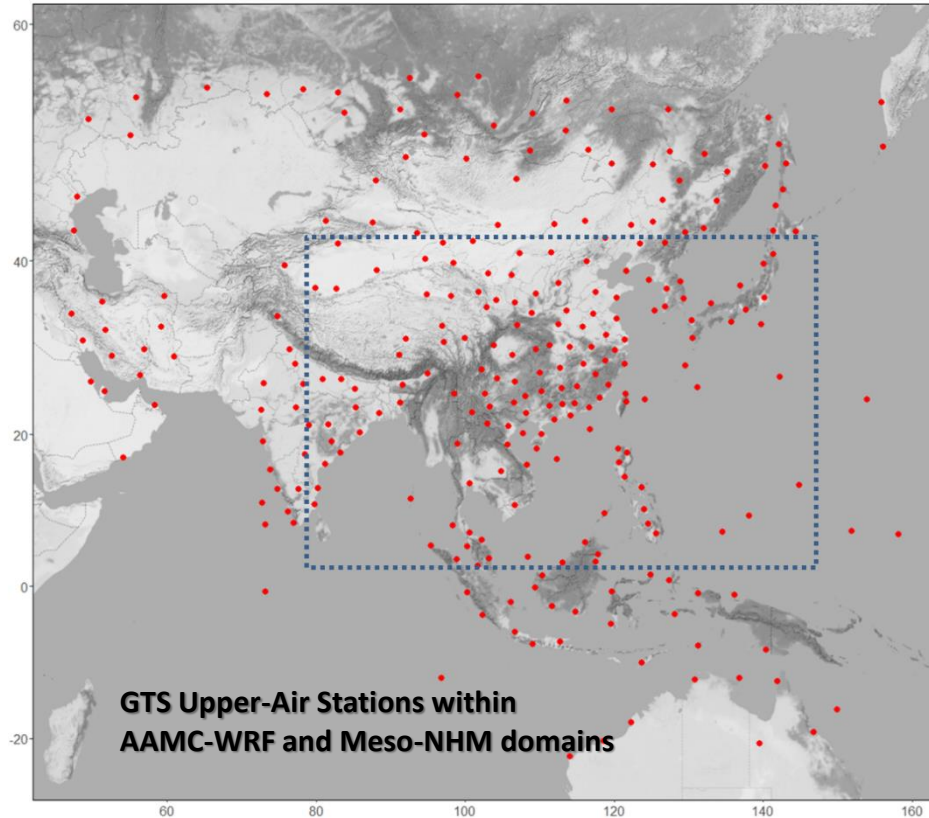
TC Prediction using 10-km AAMC-WRF



TC track verification over 2018/19 season including Western North Pacific, South China Sea, North Indian Ocean and Bay of Bengal

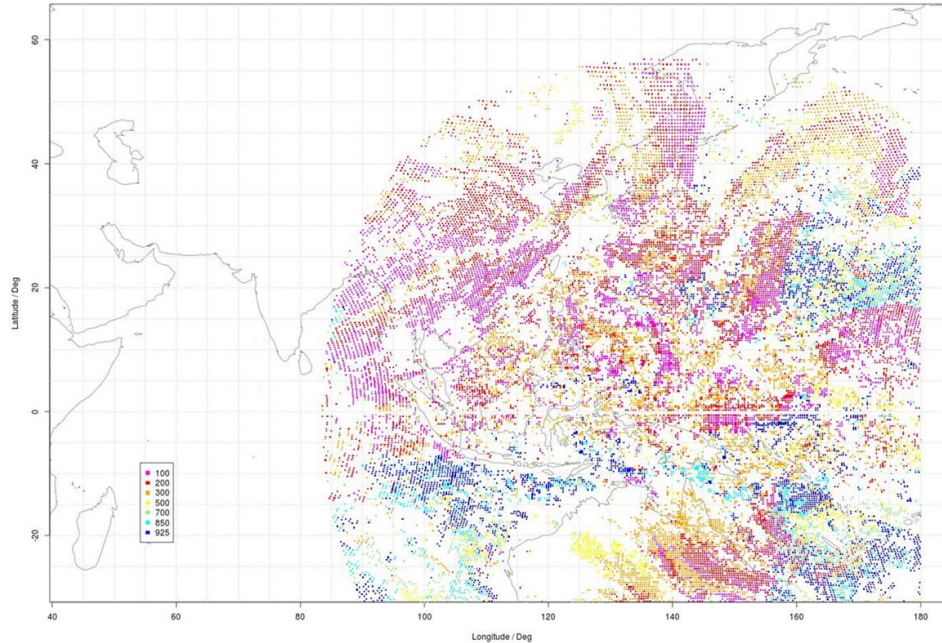


Comparison of Upper-Air Parameters

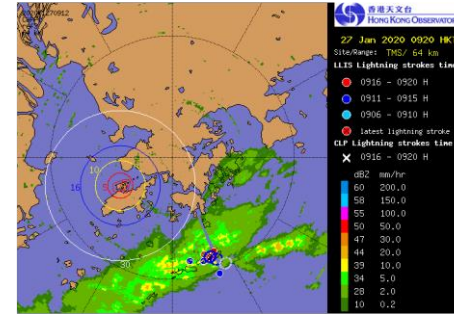


(201804 – 201906; QC applied)

Assimilation of Himawari-8 AMV

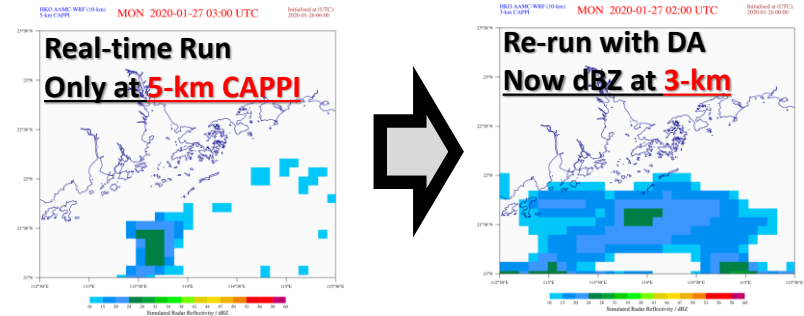


Real-time assimilation of H8 AMV into AAMC-WRF began since Jun 2020 (using WRF 3D-VAR only) – in phase starting with N-Hemisphere, then also S-Hemisphere



Radar obs. (3 km) for a case of rare winter (January) thunderstorm in Hong Kong

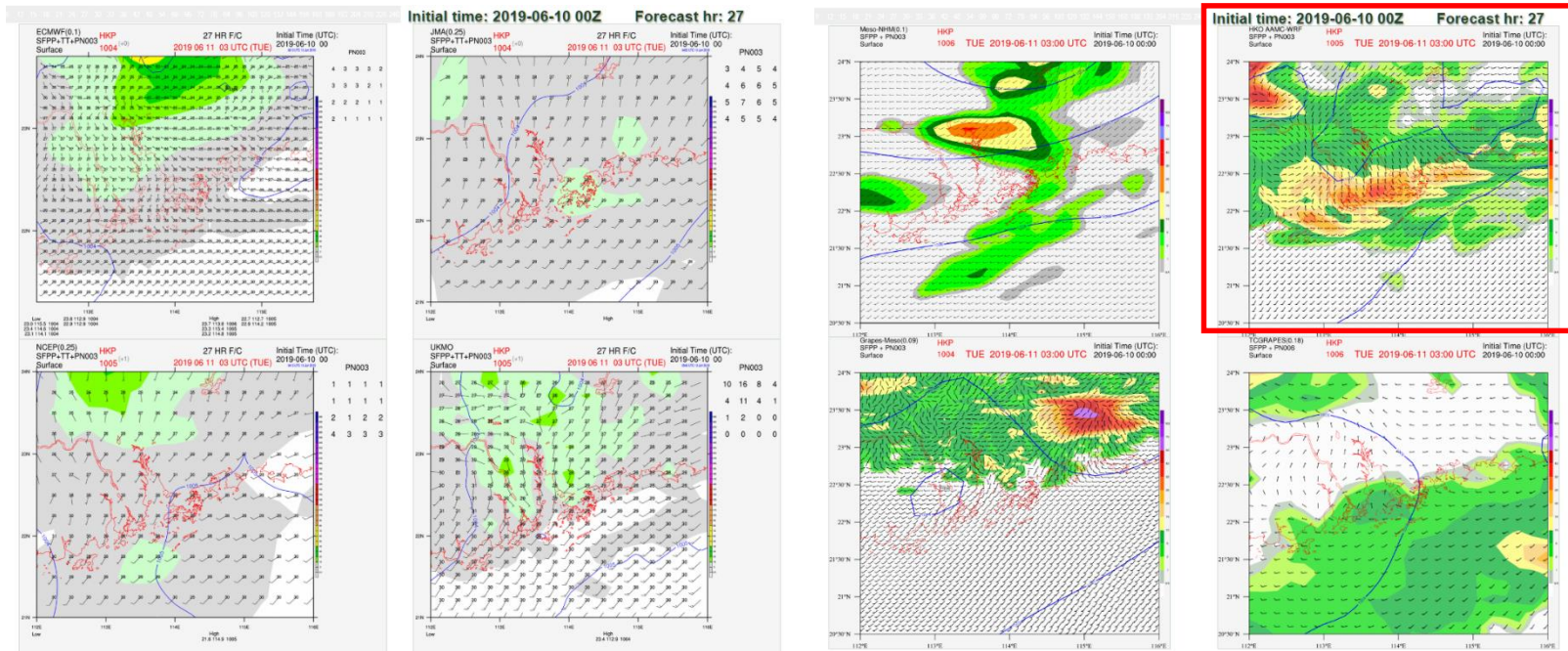
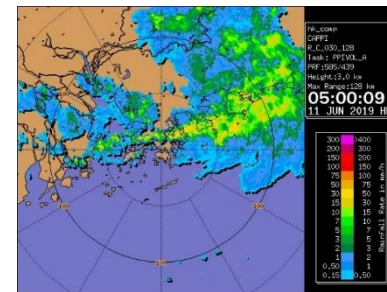
Simulated radar reflectivity from WRF (CAPPI)



Chan, Hon and Li, 2020: A rare winter thunderstorm event near Hong Kong. Atmosfera, <https://www.revistascca.unam.mx/atm/index.php/atm/article/view/52840>

A Recent Rainstorm in Hong Kong

- Narrow, line-shaped rainbands pose some of the greatest challenges
- HKO's "NWP Viewer" compares all available models (global+regional)



Verification of Short-Term QPF by NWP

Short-Range QPF

Forecast Summary & CFO Input Verification 5-Day Mean/Max 6-h Rainfall 1-Day Mean/Max 6-h Rainfall Wild

Data Settings
Plot Settings

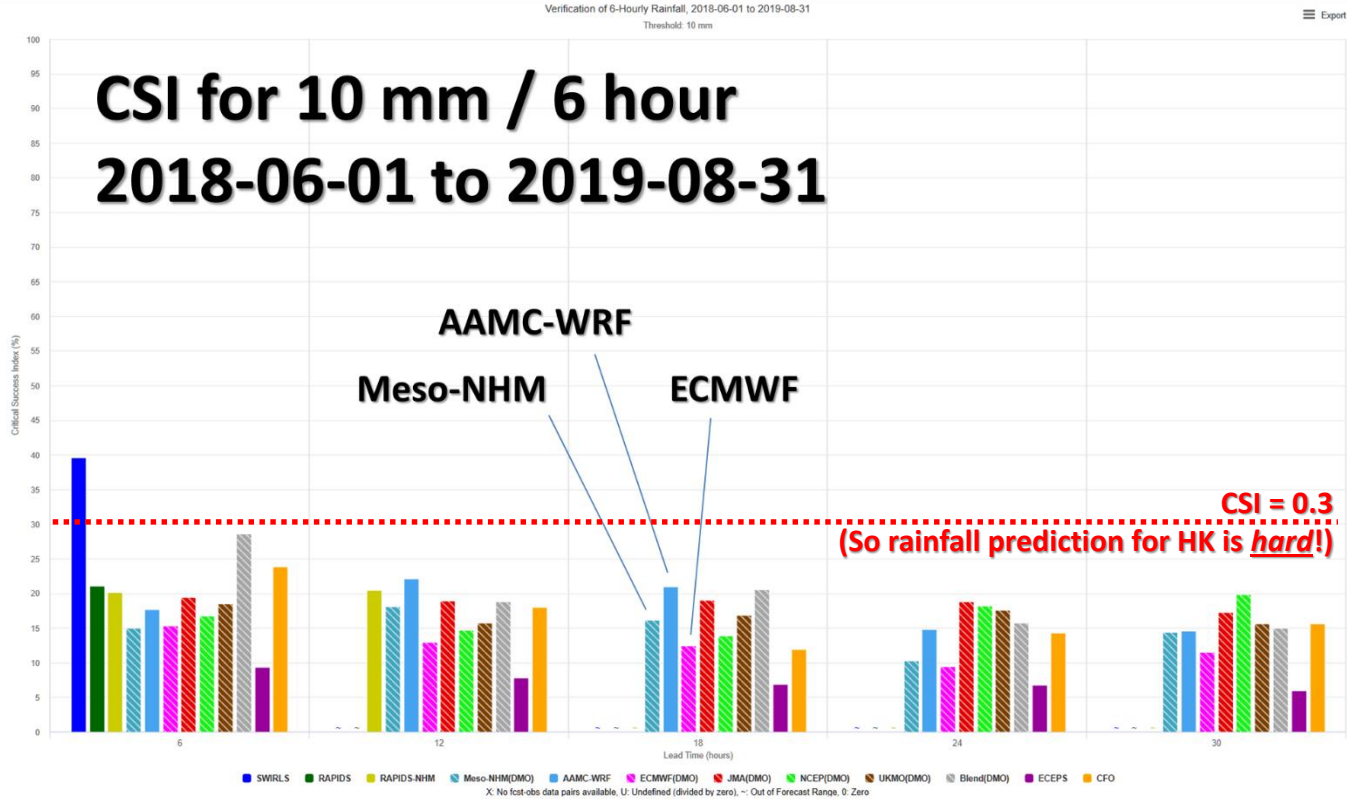
Data Retrieved:
Date: 2018-06-01 to 2019-08-31
Issue Shift Filter: All
Fcst Data Filter: 0 ~ 999 mm
Obs Data Filter: 0 ~ 999 mm
Threshold for Contingency: 10 mm

Select a Panel to Set

Model Filter Apply to All Panels
Select Models...
 DMO Calibrated

X-Axis Apply to All Panels
Lead Time

Skill Metric Apply to All Panels
Critical Success Index





The image is a satellite-based visualization of Typhoon Mangkhut. The background is a simulated infrared (IR1) satellite image showing the cloud structure of the typhoon, which is a well-developed tropical cyclone with a clear eye and dense spiral cloud bands. The typhoon is located in the Western Pacific Ocean, east of the Philippines. A red line with small dots indicates the typhoon's track, starting from the southwest and moving northeast towards the Philippines. The text in the top right corner provides the source (HKO AAMC-WRF), the name of the typhoon (TC Mangkhut), and the time of the image (2018-09-11 12UTC). A legend below the text explains the visual elements: the background is simulated IR1, the dots represent the forecast track, and the line represents the actual track.

HKO AAMC-WRF TC Mangkhut 2018-09-11 12UTC

Background = Simulated IR1
Dots = Forecast
Line = Actual



**HKO AAMC-WRF
TC Mangkhut
2018-09-13 12UTC**

Background = Simulated IR1
Dots = Forecast
Line = Actual



**HKO AAMC-WRF
TC Mangkhut
2018-09-15 12UTC**

Background = Simulated IR1
Dots = Forecast
Line = Actual

Track Verification for Mangkhut (2018)

Error (km)	ECMWF	NCEP	HWRF	TWRF	HKO AAMC
T+24	50	55	67	41	51
T+48	66	84	91	96	61

Based on common data set comprising
9 consecutive forecasts initialised
between 11 and 15 Sep 2018

Sub-kilometre Prediction for HK Int'l Airport

Our Problem Statement

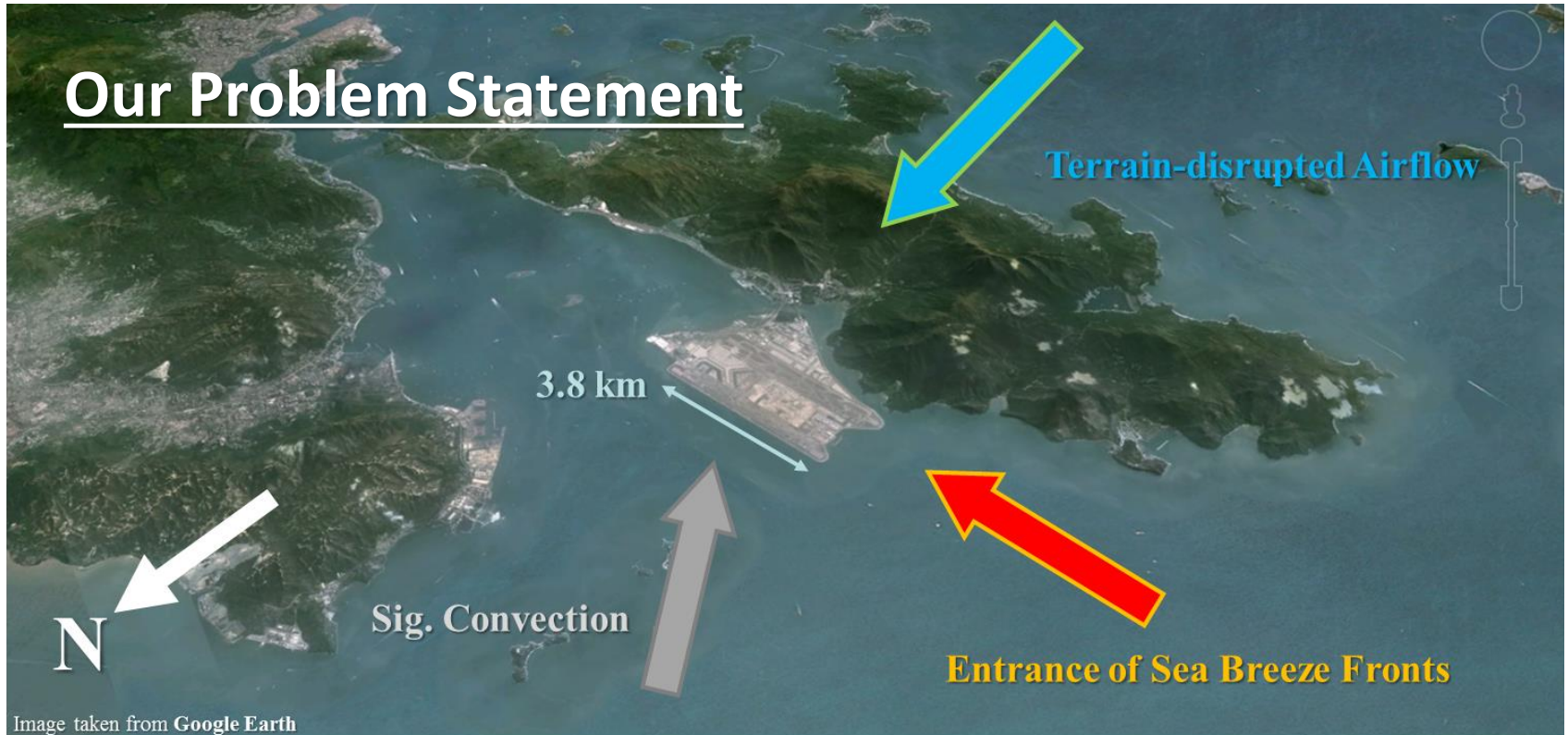
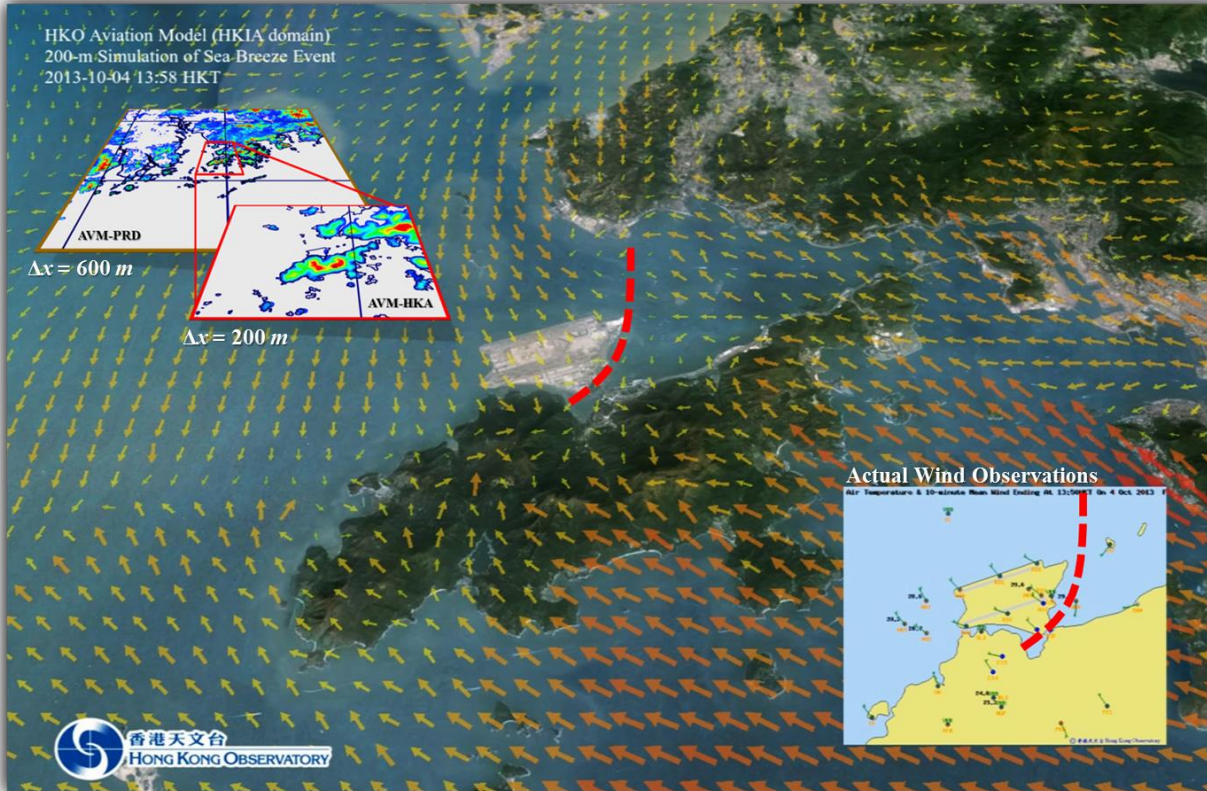


Image taken from Google Earth

The Aviation Model (AVM)



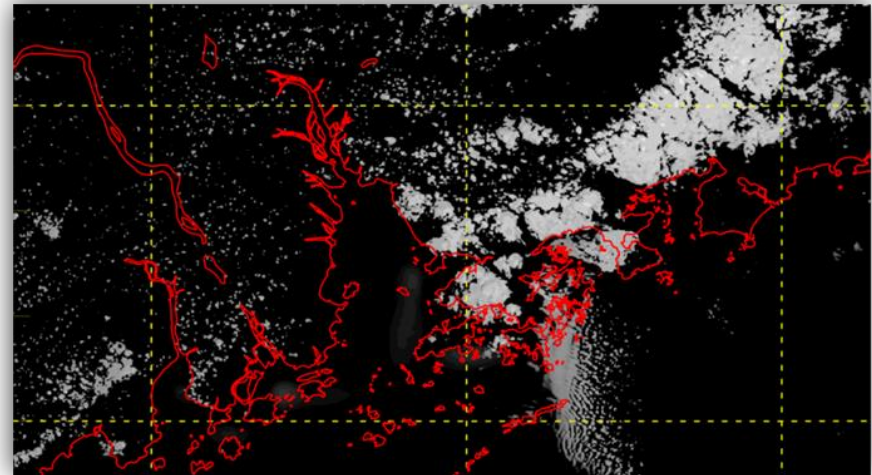
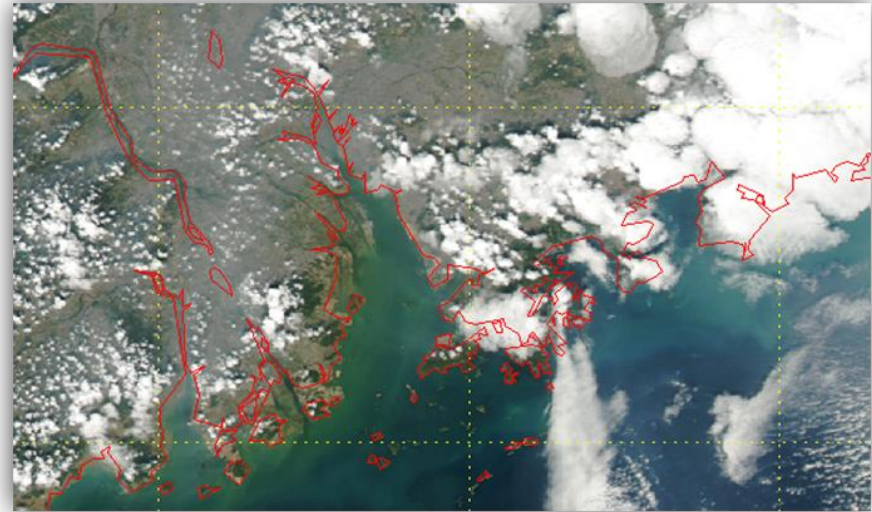
- Sub-km WRF for HKIA
- 600-m/200-m domains
- Hourly runs up to T+12
- Inner domain 581 x 581
- Expanding to 901 x 901
- Run in “LES mode” (i.e. without Boundary Layer Scheme)

What does 200-m resolution look like?

Top: Cloud distribution over Pearl River Estuary during passage of an E'ly wind front as observed on MODIS (true colour)

Bottom: Simulated satellite imagery (radiative transfer computations using RTTOV) based on AVM forecast

(Grid-lines at 1° latitude/longitude)

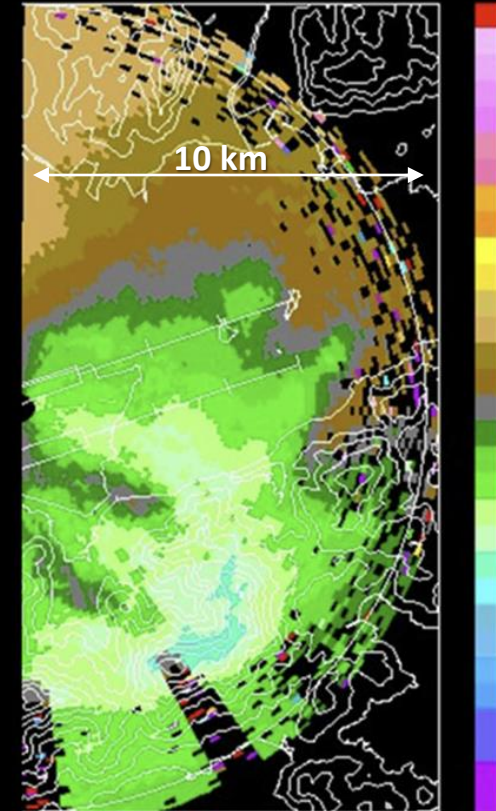
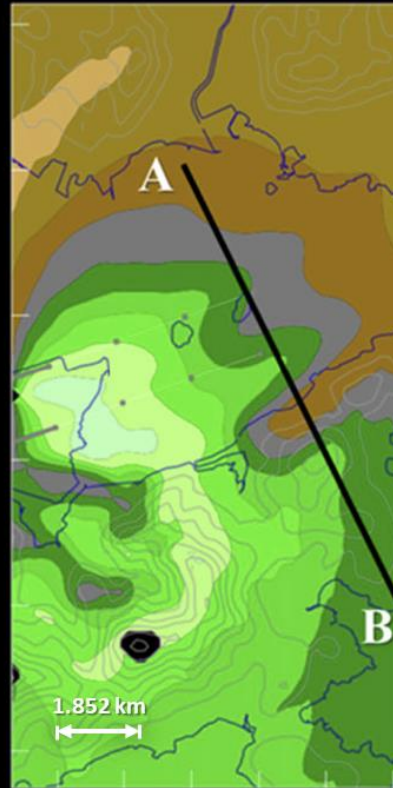
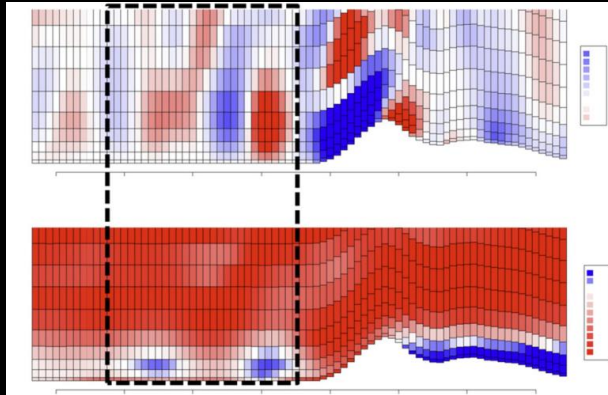


Prediction of Mountain Waves near HKIA

Right: Observed Doppler LIDAR PPI
(6-deg elevation, $\Delta r = 105\text{ m}$)

Left: Simulated LIDAR PPI by AVM
(5-hour forecast, $\Delta x = 200\text{ m}$)

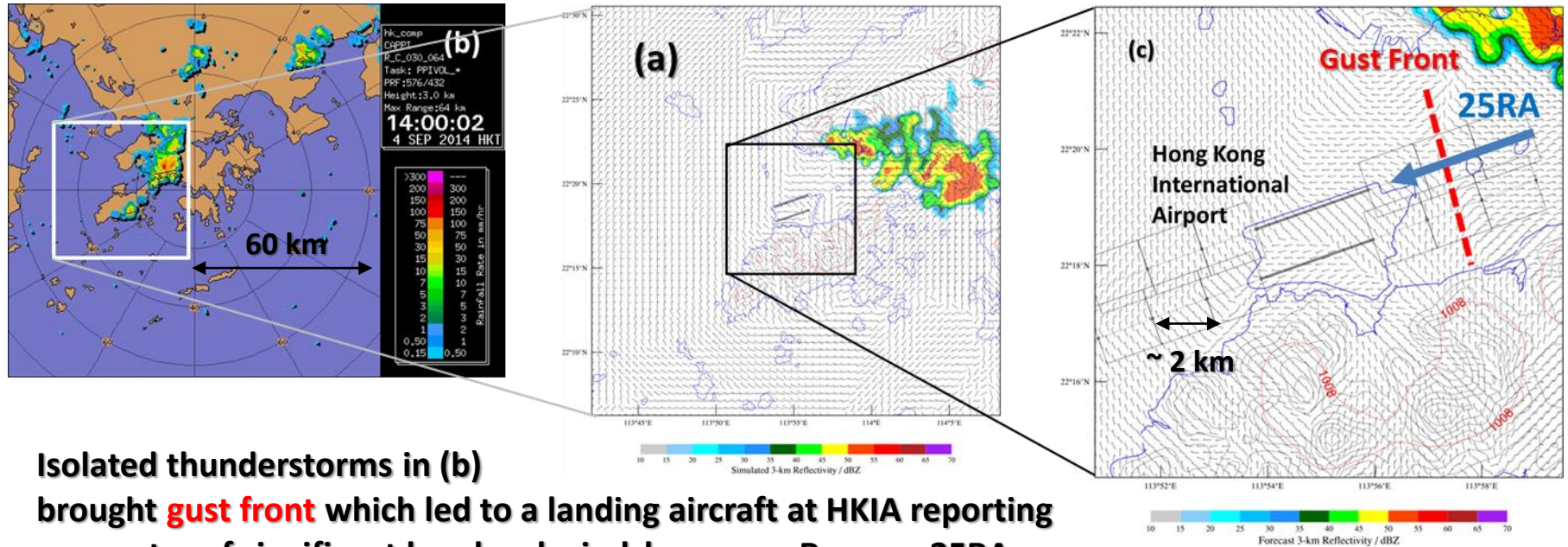
Below: Cross-section from A (left) to B (right)



Chan and Hon (2015): Performance of super high-resolution numerical weather prediction model in forecasting terrain-disrupted airflow at the Hong Kong International Airport: Case studies. *Meteorol. Apps.* **23**, 101-114.

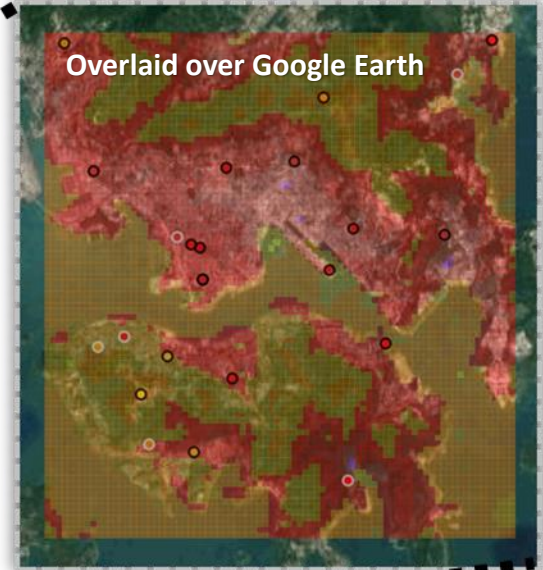
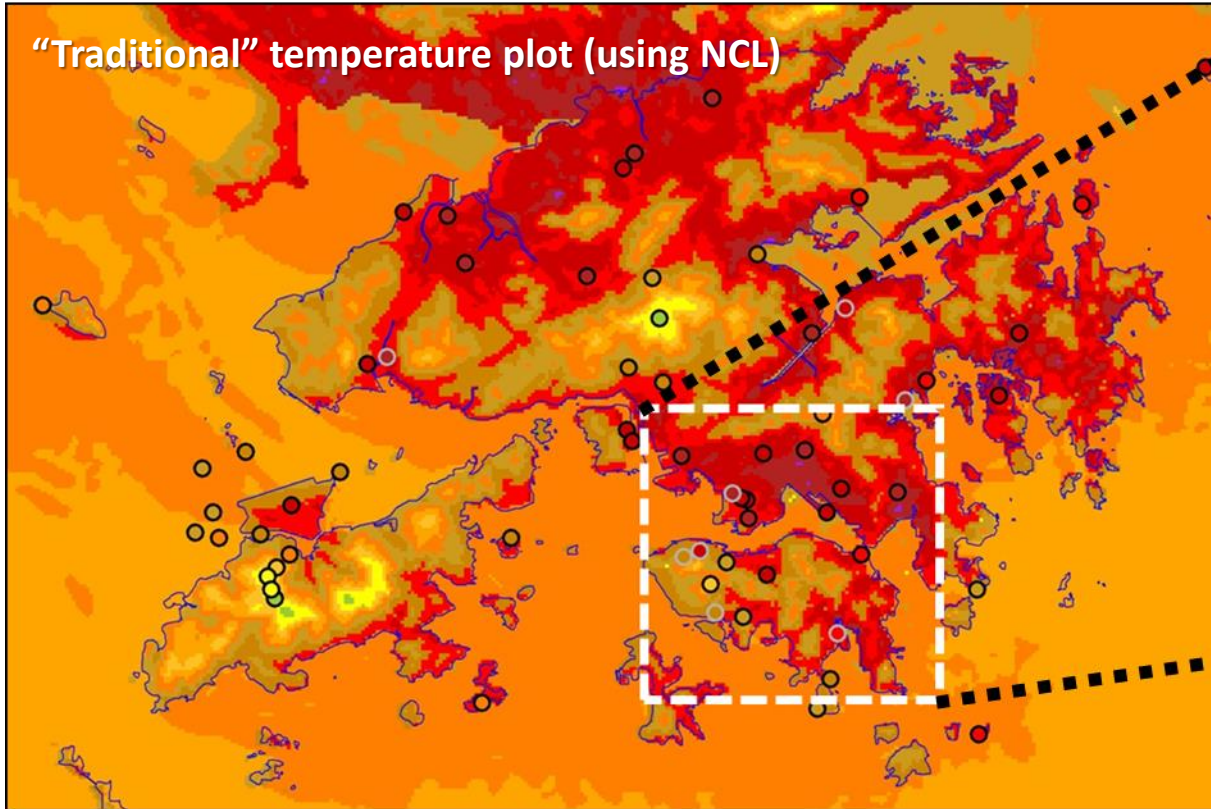
<https://doi.org/10.1002/met.1534>

Prediction of Gust Front near HKIA



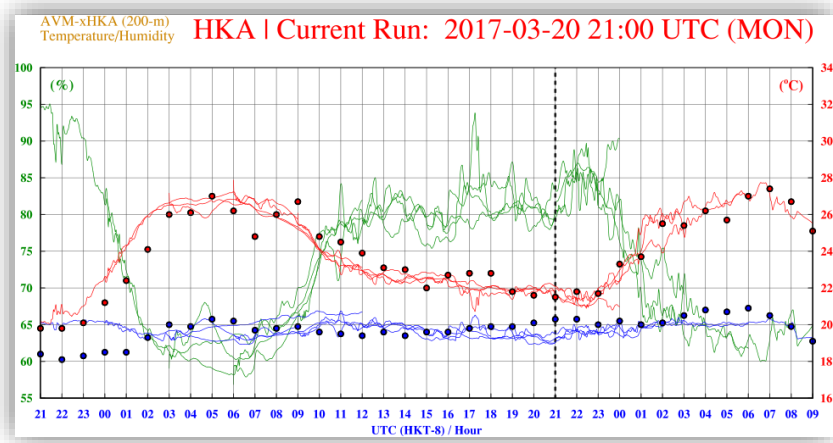
Isolated thunderstorms in (b) brought **gust front** which led to a landing aircraft at HKIA reporting encounter of significant low-level windshear over Runway 25RA. Event was correctly predicted by 200-m AVM in (a) and (c).

Urban-scale Prediction using AVM



Fine-resolution temperature prediction (each pixel = 200 m)

Urban-scale Prediction using AVM



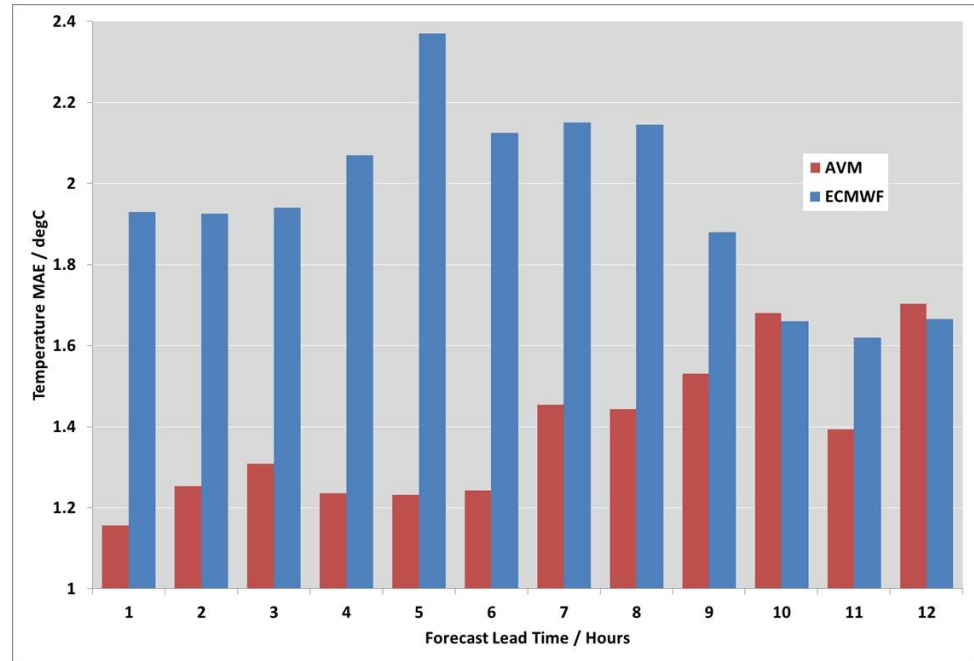
Lines – Rapid-updating AVM forecasts (hourly)

Dots – Verifying observations at each hour

Red – Temperature

Blue – Dew point

Green – Humidity



Benefits over ECMWF in short-term forecasts for the Hong Kong International Airport (201801 - 201906)

Short-term Prediction of Tornado/Waterspout

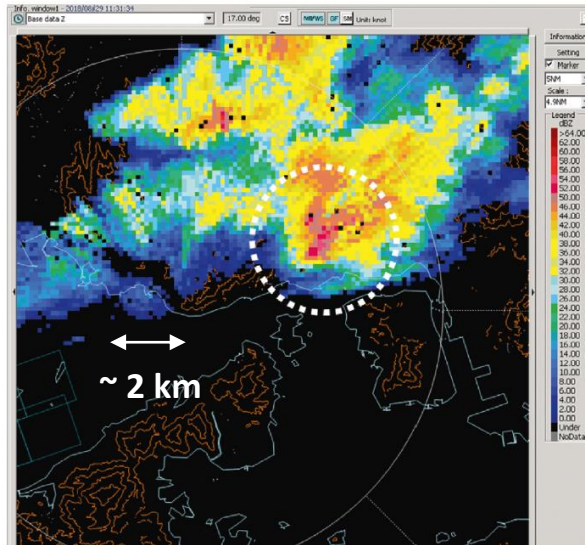


(a)

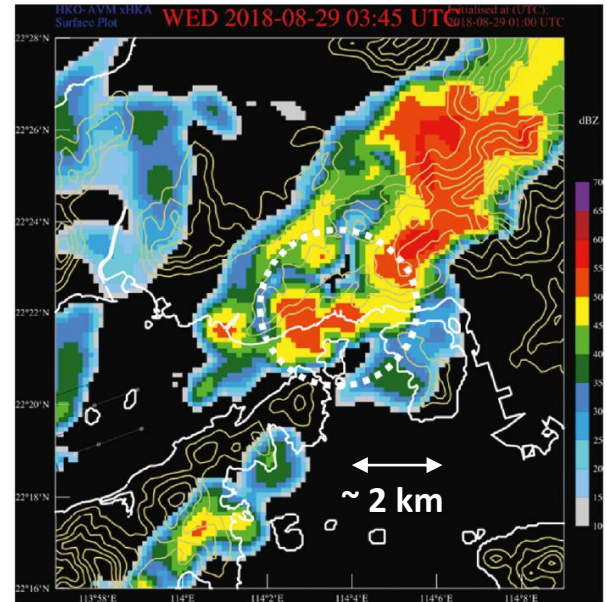
**Tornado observed near Ting Kau, HK on 29 August 2018
(No damage nor casualty)**

Acknowledgements:

<https://www.scmp.com/news/hong-kong/health-environment/article/2161821/waterspout-spotted-near-hong-kongs-ting-kau-bridge>



(a)



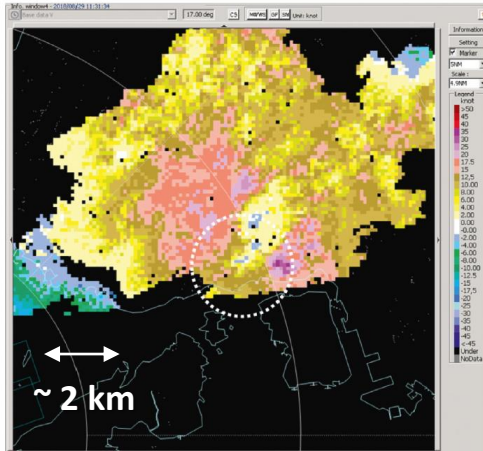
(b)

Left: Terminal Doppler Weather Radar (TDWR) dBZ

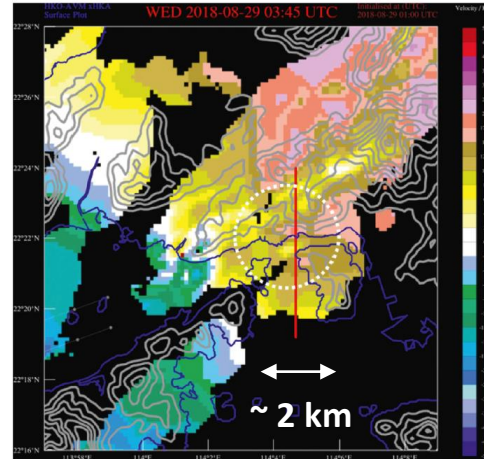
Right: Forecast dBZ by 200-m AVM

White Circle: Storm cell associated with tornado

Short-term Prediction of Tornado/Waterspout

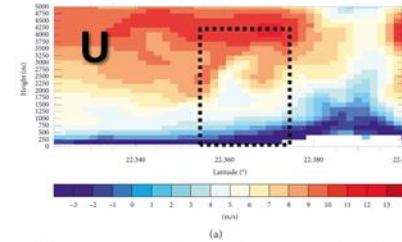


(a)

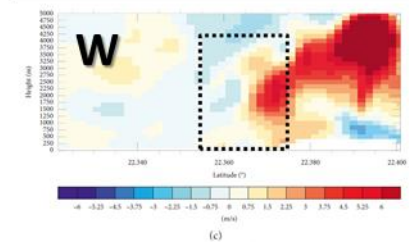


(b)

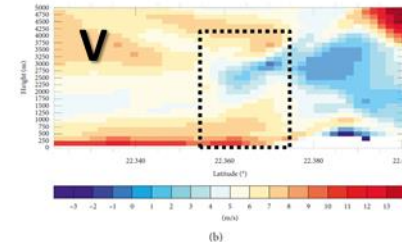
Vertical cross-sections taken along red line demonstrating structure of simulated vortex and cloud system:



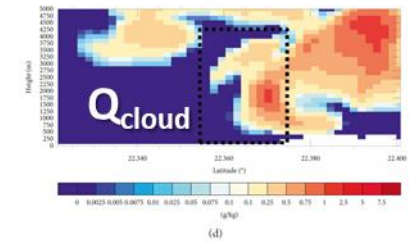
(a)



(c)



(b)



(d)

Left: TDWR Doppler velocity PPI
Right: Forecast Doppler velocity by 200-m AVM
White Circle: Velocity couplet associated with meso-/micro-vortex leading to tornado

All very nice & amazing so far, but...

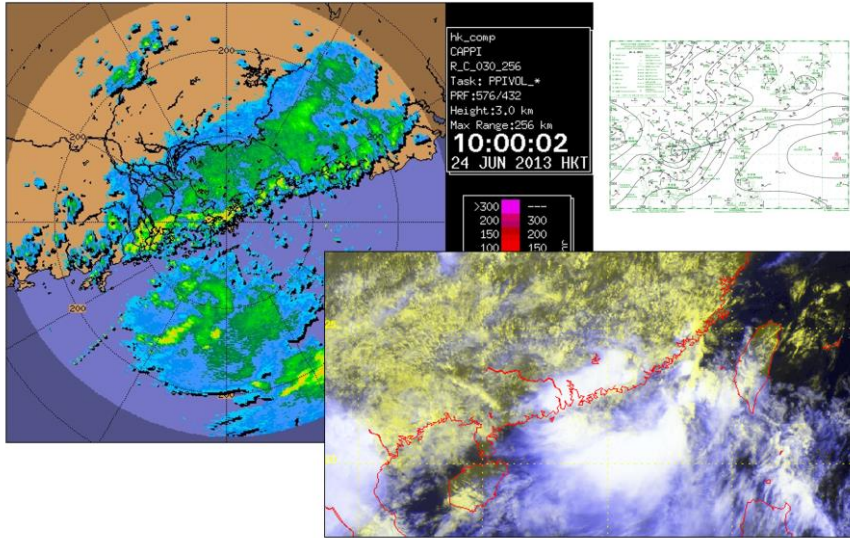
model output provides a better representation of some weather elements than others, for example, surface temperature is often quite well resolved (at least away from steep surface orography), whereas precipitation is often much less well resolved.

However, despite these advances, it is well known that forecasts from even the very best models can often go badly wrong. This is most obvious in forecasts several days ahead and is due to the chaotic nature of the atmosphere. We forecast the weather by starting the model from an analysis of the state of the atmosphere based on the latest observations that are taken all around the world. The model then calculates how the atmosphere will change and evolve from this initial

(WMO-No. 1091)

All very nice & amazing so far, but...

Red Rainstorm on 24th Jun 2013



Red Rainstorm on 24th Jun 2013

Meso-NHM QPF
Ensemble

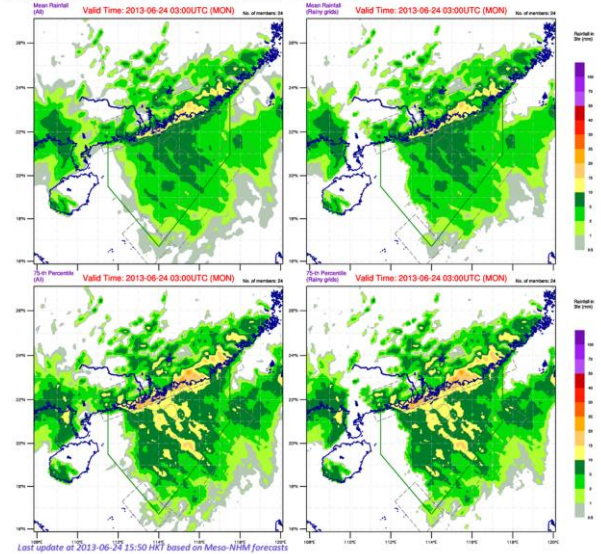
Forecast at:
2013-06-24 03Z
(MON)

-3 +3
-6 +6
-12 +12
-24 +24

Stamp Map

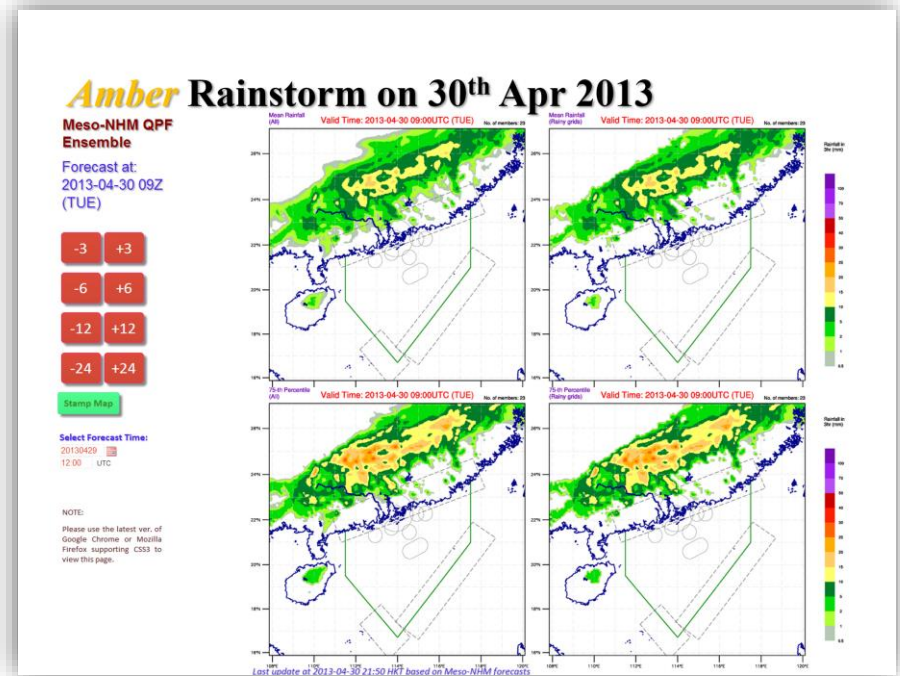
Select Forecast Time:
20130624 03:00 UTC

NOTE:
Please use the latest ver. of
Google Chrome or Mozilla
Firefox supporting CSS3 to
view this page.



Sometimes models are spot on for one type of situation...

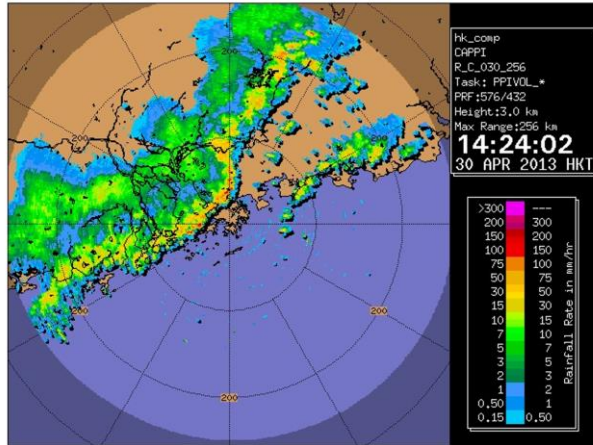
All very nice & amazing so far, but...



Given this forecast, what's your prediction for this episode?

All very nice & amazing so far, but...

Amber Rainstorm on 30th Apr 2013

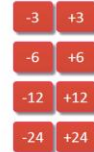


14 HKT = 06 UTC

Amber Rainstorm on 30th Apr 2013

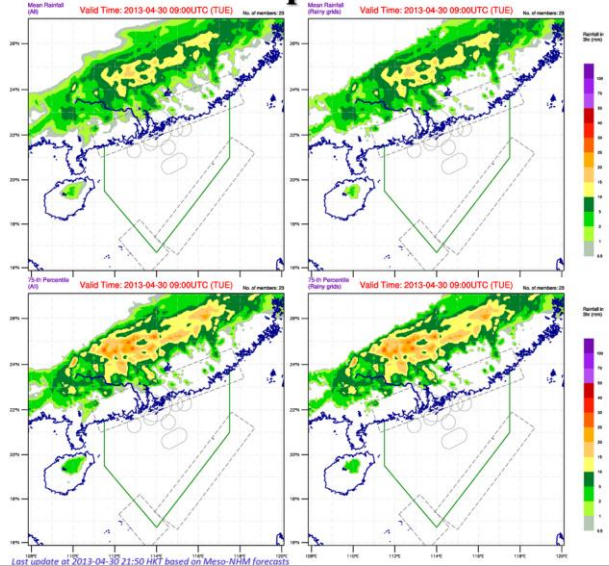
Meso-NHM QPF
Ensemble

Forecast at:
2013-04-30 09Z
(TUE)



Select Forecast Time:
20130429 12:00 UTC

NOTE:
Please use the latest ver. of
Google Chrome or Mozilla
Firefox supporting CSS3 to
view this page.



Squall line reached Hong Kong 3 hours earlier than forecast time

All very nice & amazing so far, but...

“Fine Prints”

- High-resolution model products
 - **Are only as good as the model itself...**
 - Post-processing allows (very) realistic presentation
 - But liable to timing + position + intensity errors
 - Therefore requires **even more** expert judgement
- Current state of the science
 - Challenging issues:
 - Form of convection
 - Location / timing of initiation

“Gentle Reminder”

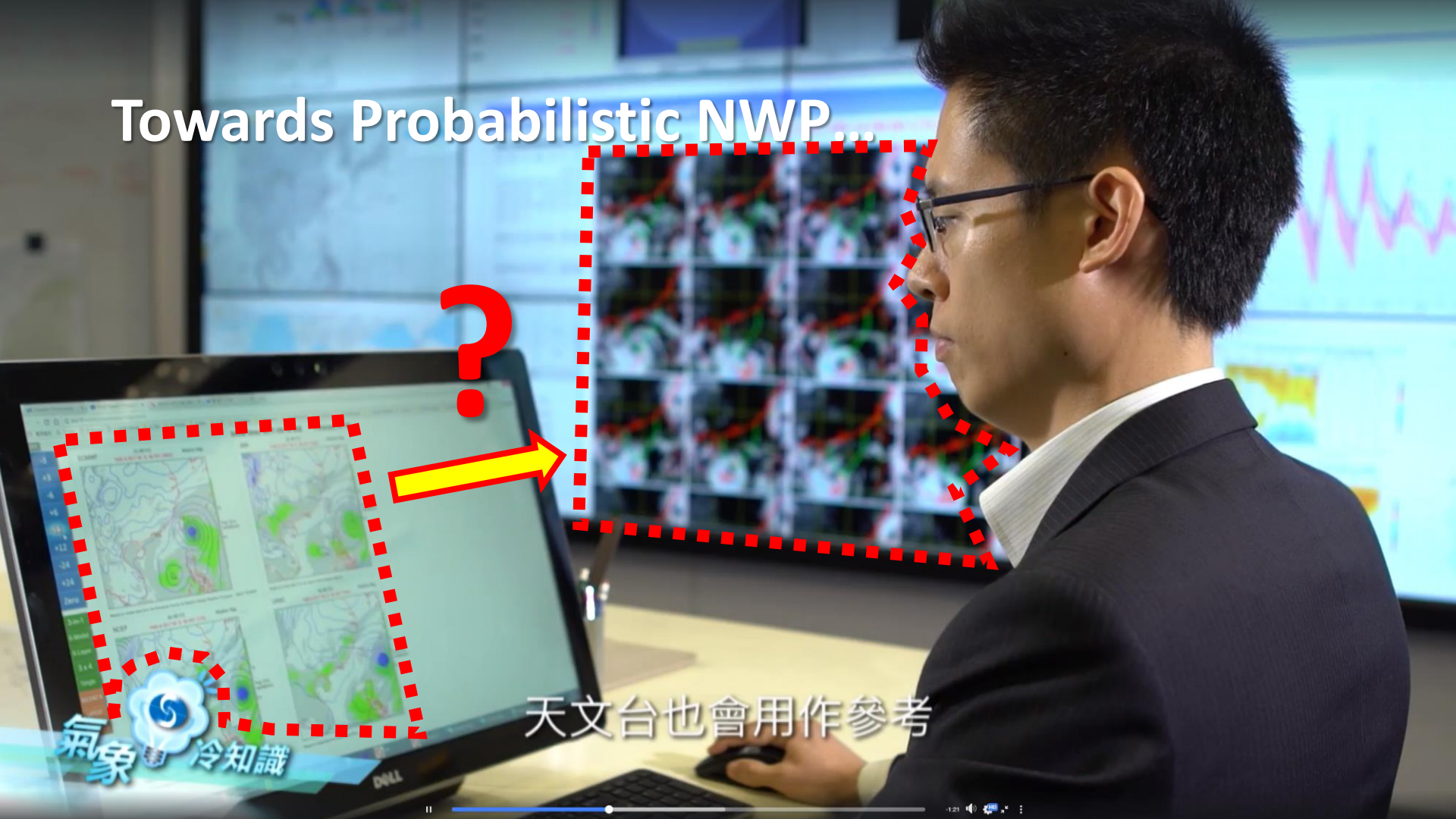
- *Know thyself & thy enemies...*
 - Strengths & limitations of different models
- *3 cobblers make 1 Zhuge Liang*
 - Multi-model / Multi-member / Multi-scenario
- “Low-probability High-impact Events”
 - How to interpret EPS “worst case”?
- High-res. NWP models v. sensitive to input
 - Your expert judgment of even greater value



- *****Not all errors post-processable*****

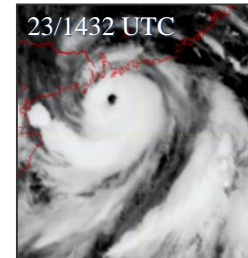
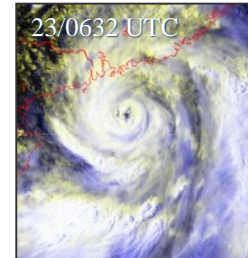
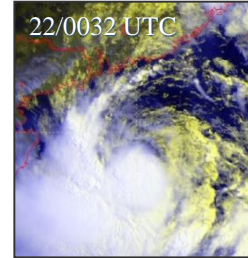
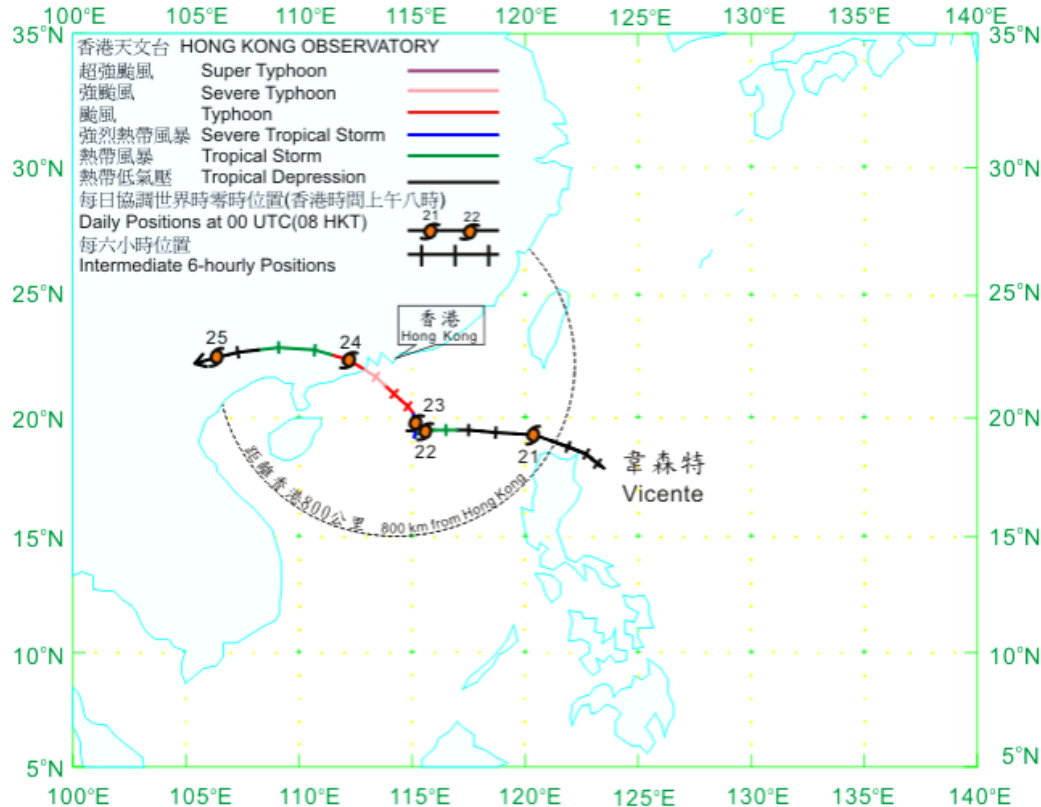
Recurrent themes Weather Forecasters are reminded of during HKO’s “Pre-Rain Seminars”

Towards Probabilistic NWP...



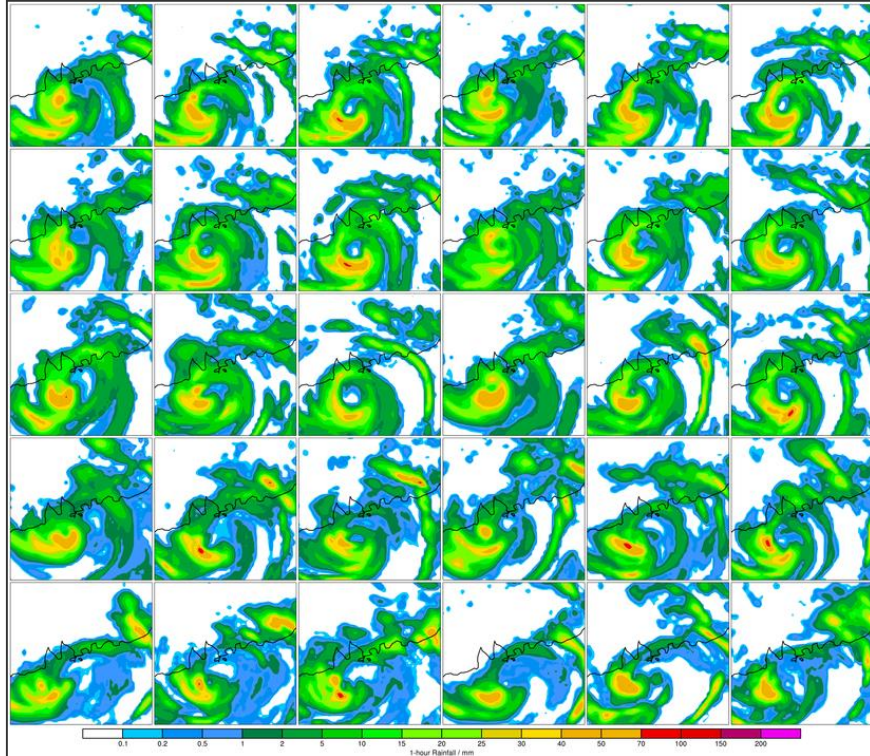
天文台也會用作參考

It started with a TC Signal No. 10...

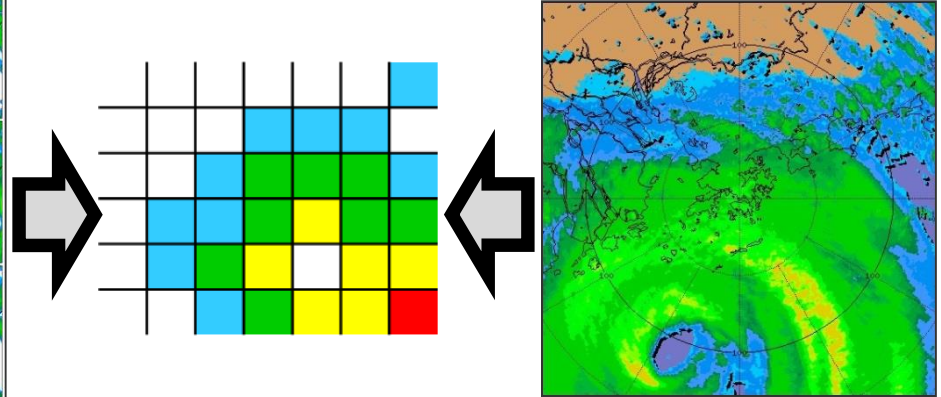


T1	21 st July 15:40 HKT
L3	23 rd July 05:20 HKT
▲8 NE 東北	23 rd July 17:40 HKT
⚡9	23 rd July 23:20 HKT
+10	24 th July 00:45 HKT
▼8 SE 東南	24 th July 03:35 HKT
L3	24 th July 10:10 HKT
T1	24 th July 14:40 HKT
--	24 th July 23:15 HKT

The Case of Vicente (2010)



Experimental 10-km ensemble setup with 30 members

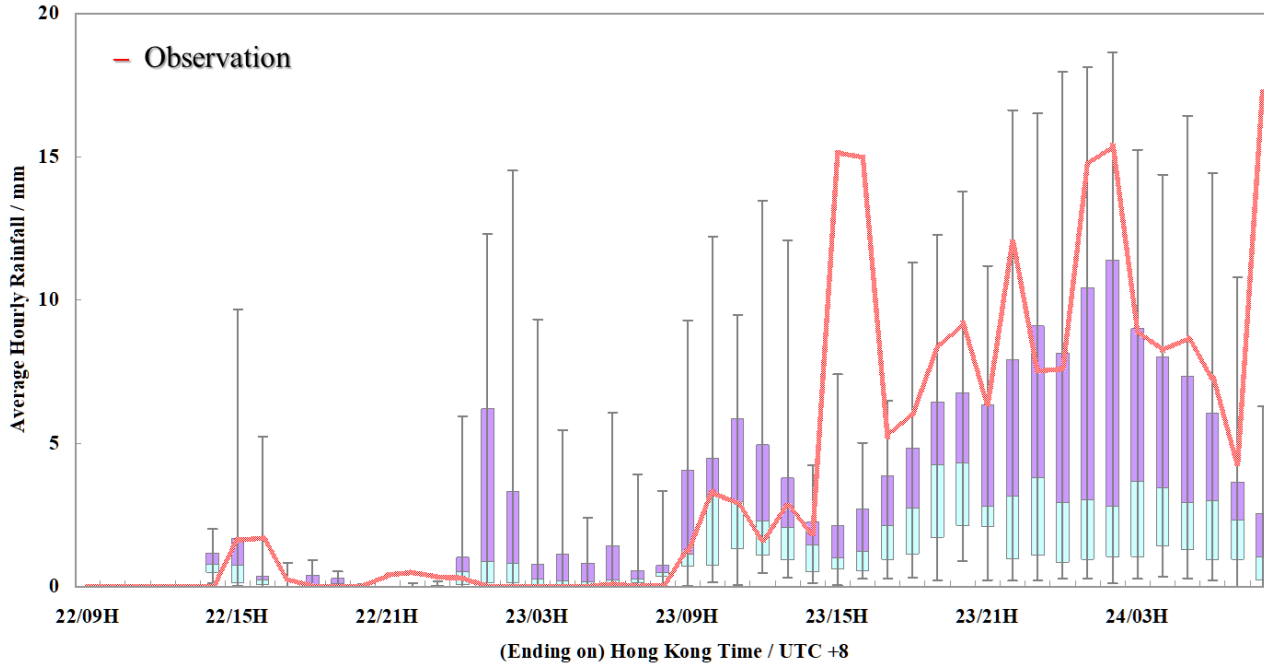


HKO TMS Radar Observations

Original plan includes studying:
reproducibility of weather extremes,
verification of fractional/spatial coverage
of rainfall, etc. (using NHM)

Or, Hon and Wong (2013)
Numerical Studies on Severe Typhoon Vicente
<https://www.hko.gov.hk/en/publica/reprint/files/r1060.pdf>

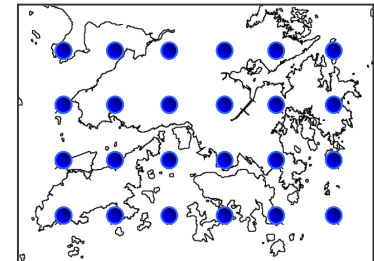
The Case of Vicente (2010) - Rainfall



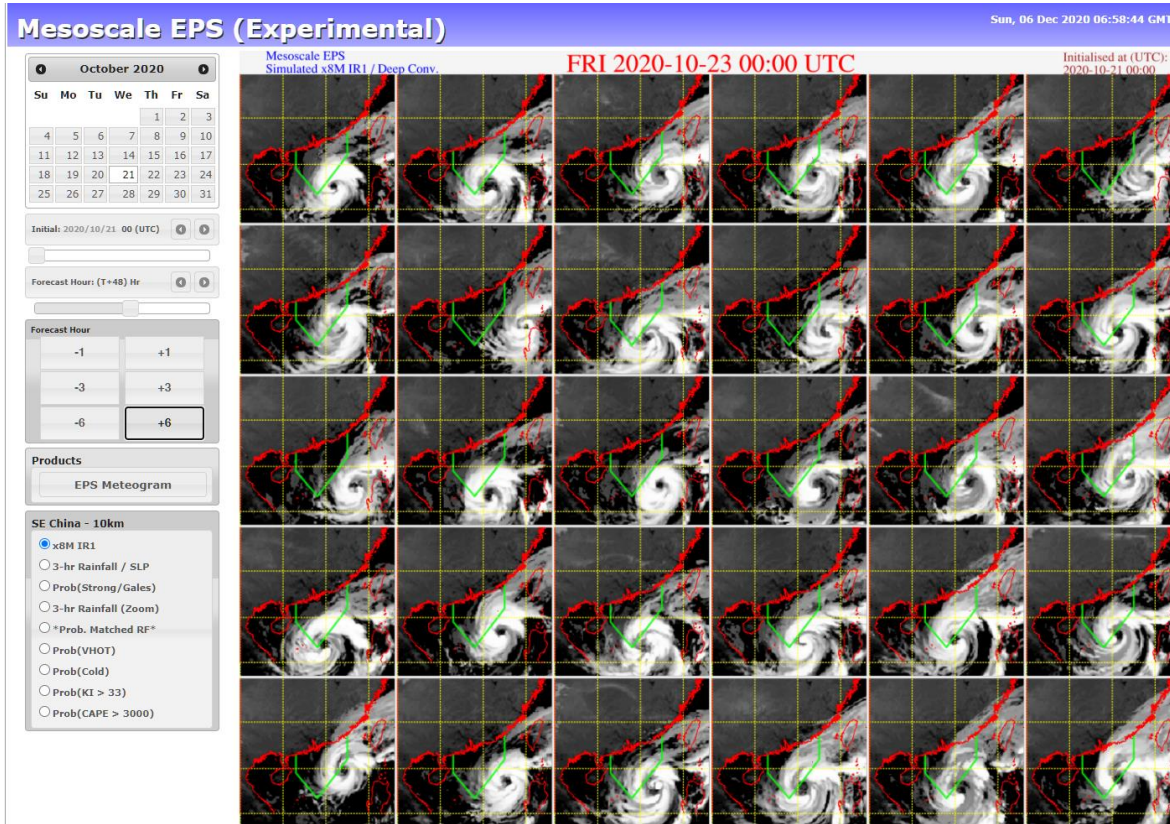
Recorded (red) and forecast (box-and-whisker) hourly average rainfall over the territory



HKO rain gauges (top) and grid-points (bottom) used in calculation of "Average Rainfall"



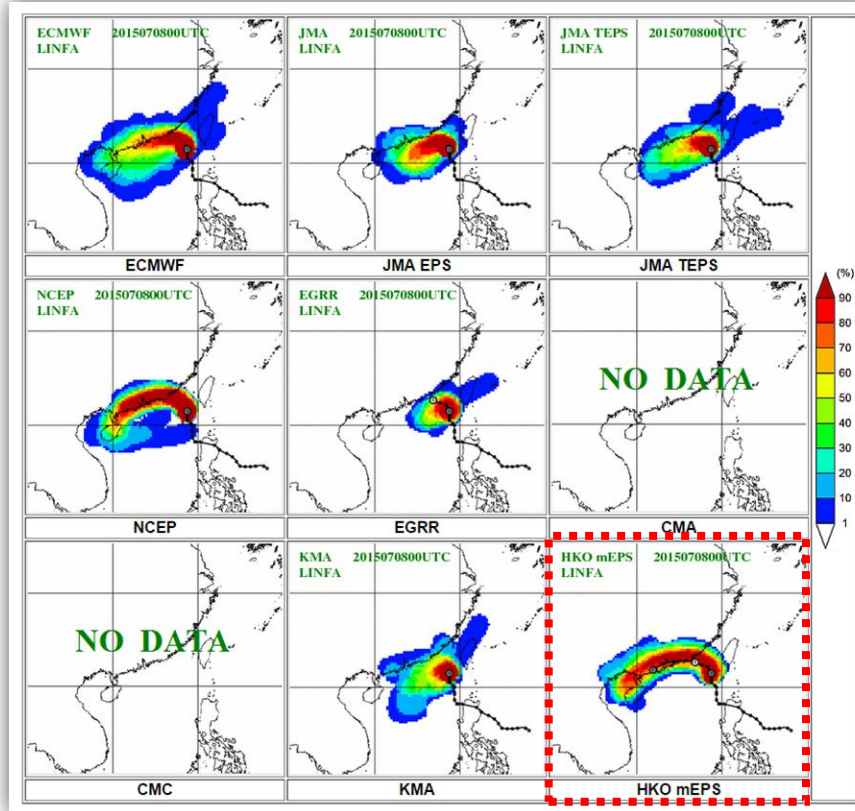
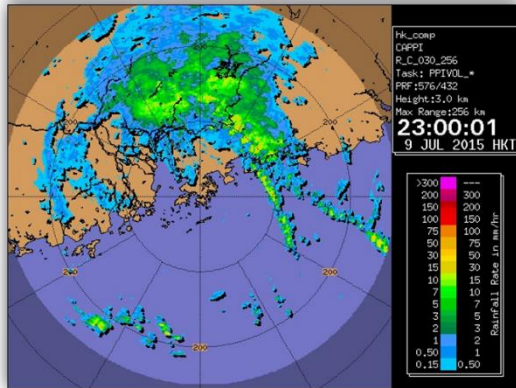
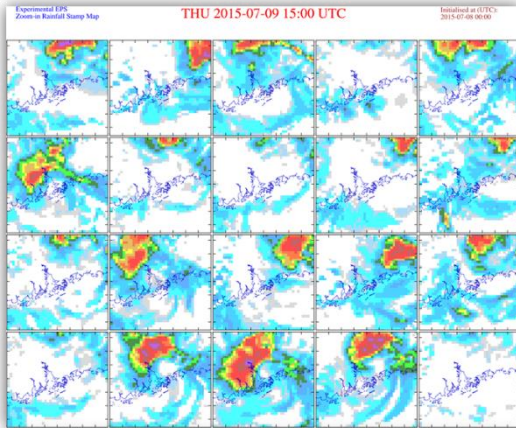
Mesoscale Ensemble Prediction System



- WRF-based 10-km EPS
- NCEP-GEFS perturbations
- 4 runs per day up to T+84
- Expanded from 20 to 30 ensemble members

- Focusing on Southern China and northern part of South China Sea
- 301 x 251 x 36 grid-points

TC Prediction using MEPS



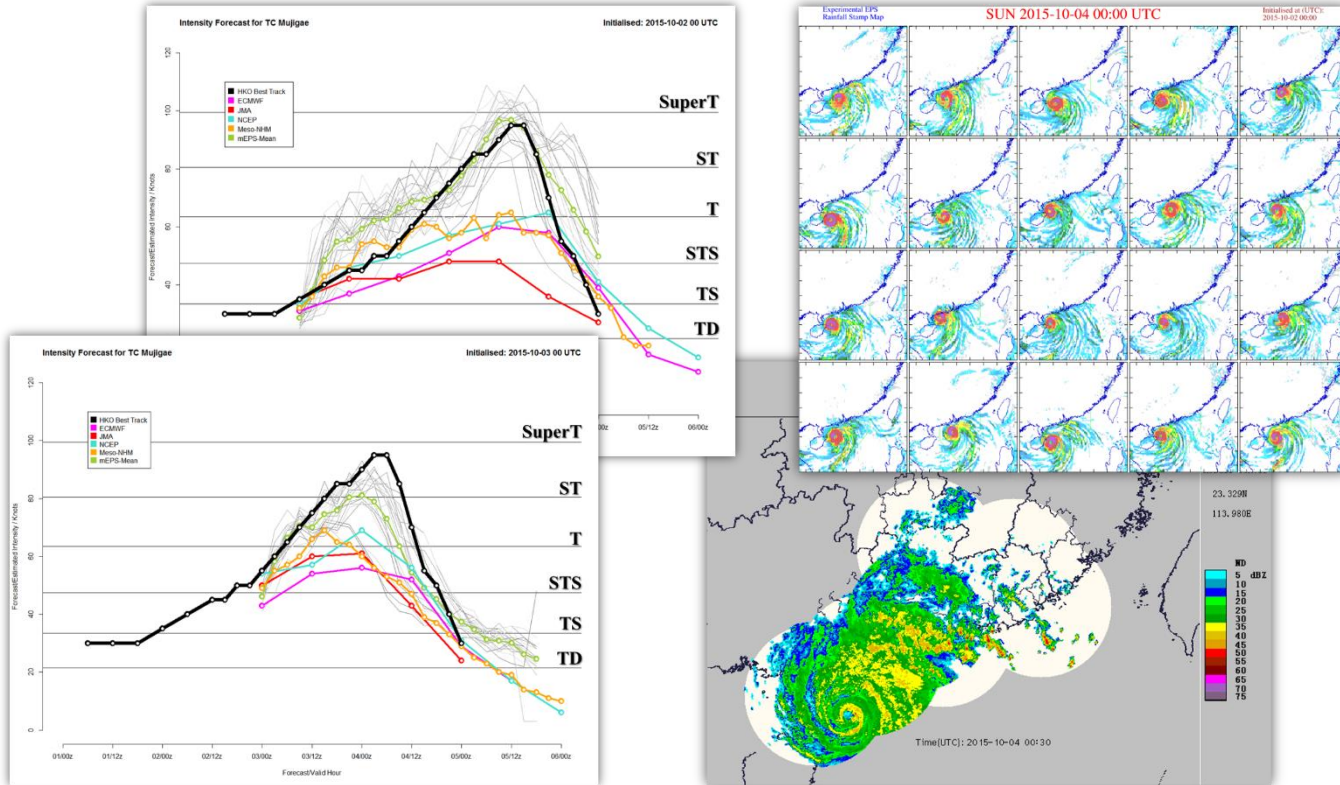
TC Linfa (2015)

Challenging track skirting just N of Hong Kong

MEPS captured asymmetry of rainbands and movement over inland areas

ECMWF, JMA, KMA, EGRR all too far south

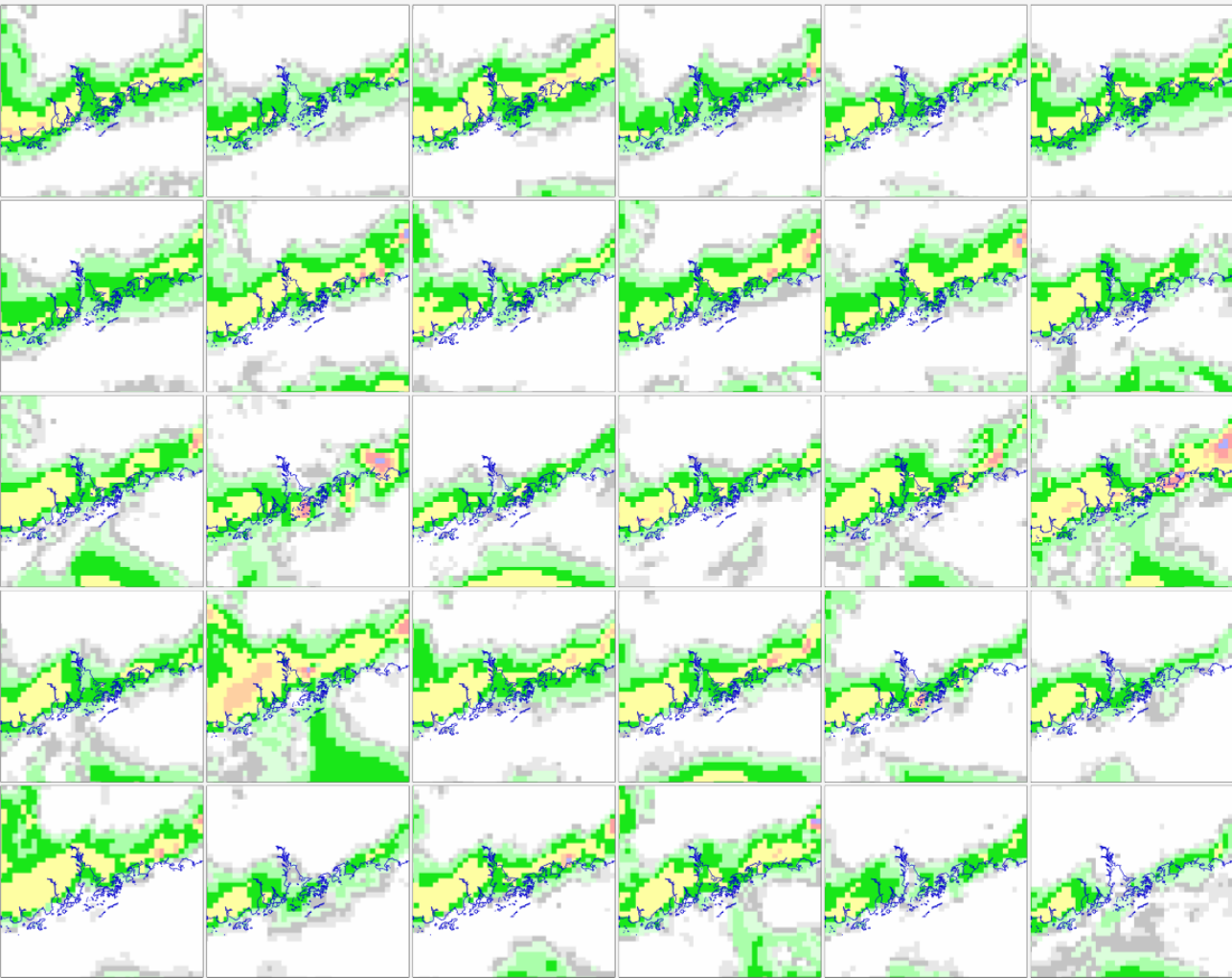
TC Prediction using MEPS



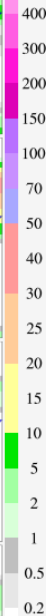
TC Mujigae (2015)

A case of Rapid Intensification well-captured by MEPS

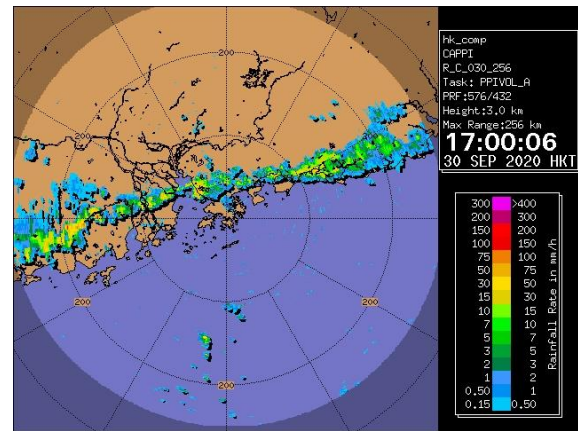
Also a reasonable depiction of the tight spiral band structure



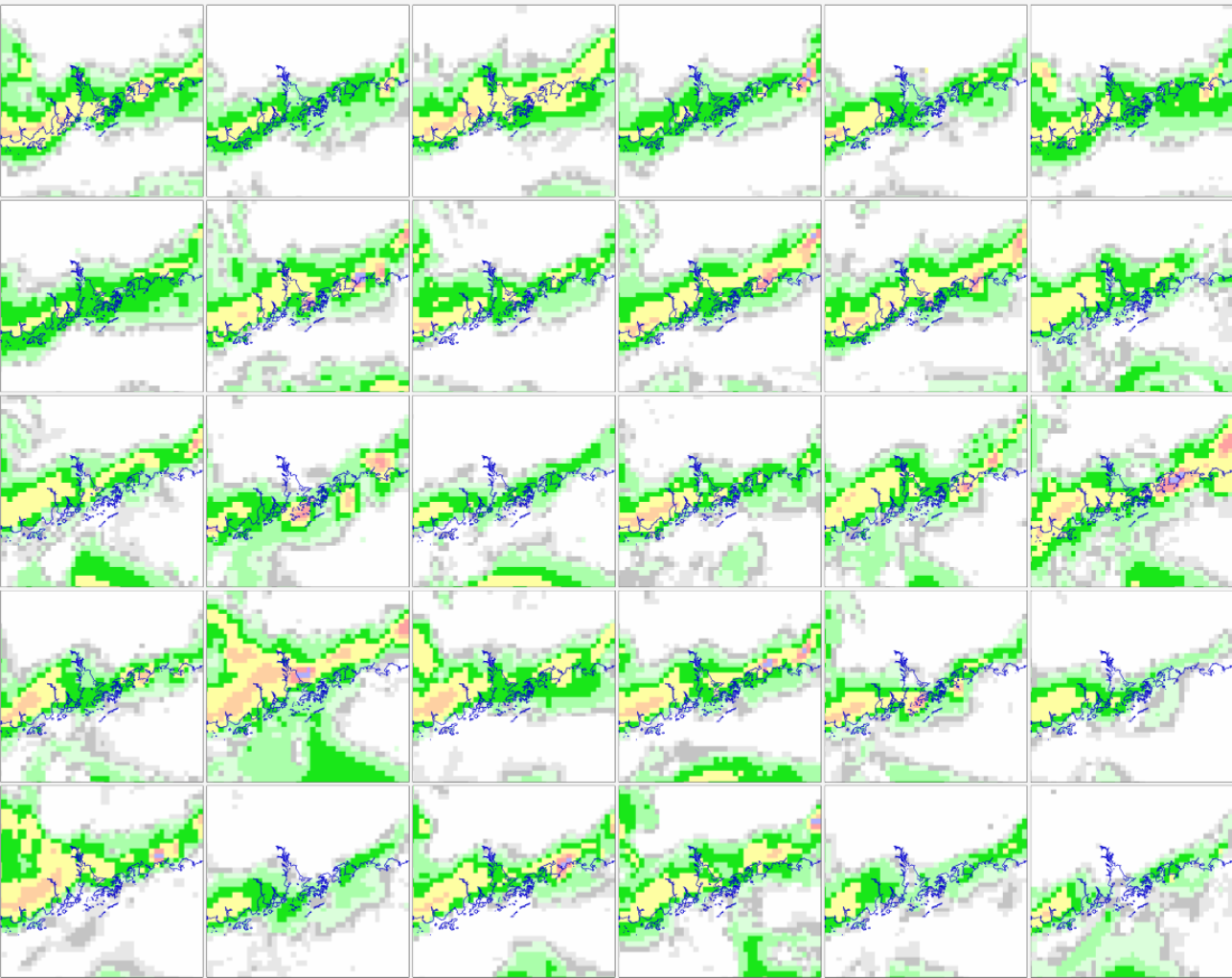
mm



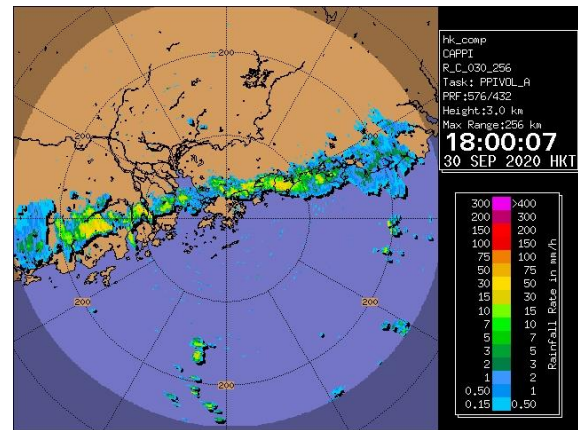
Black Rainstorm in Hong Kong (30 Sep 2020)



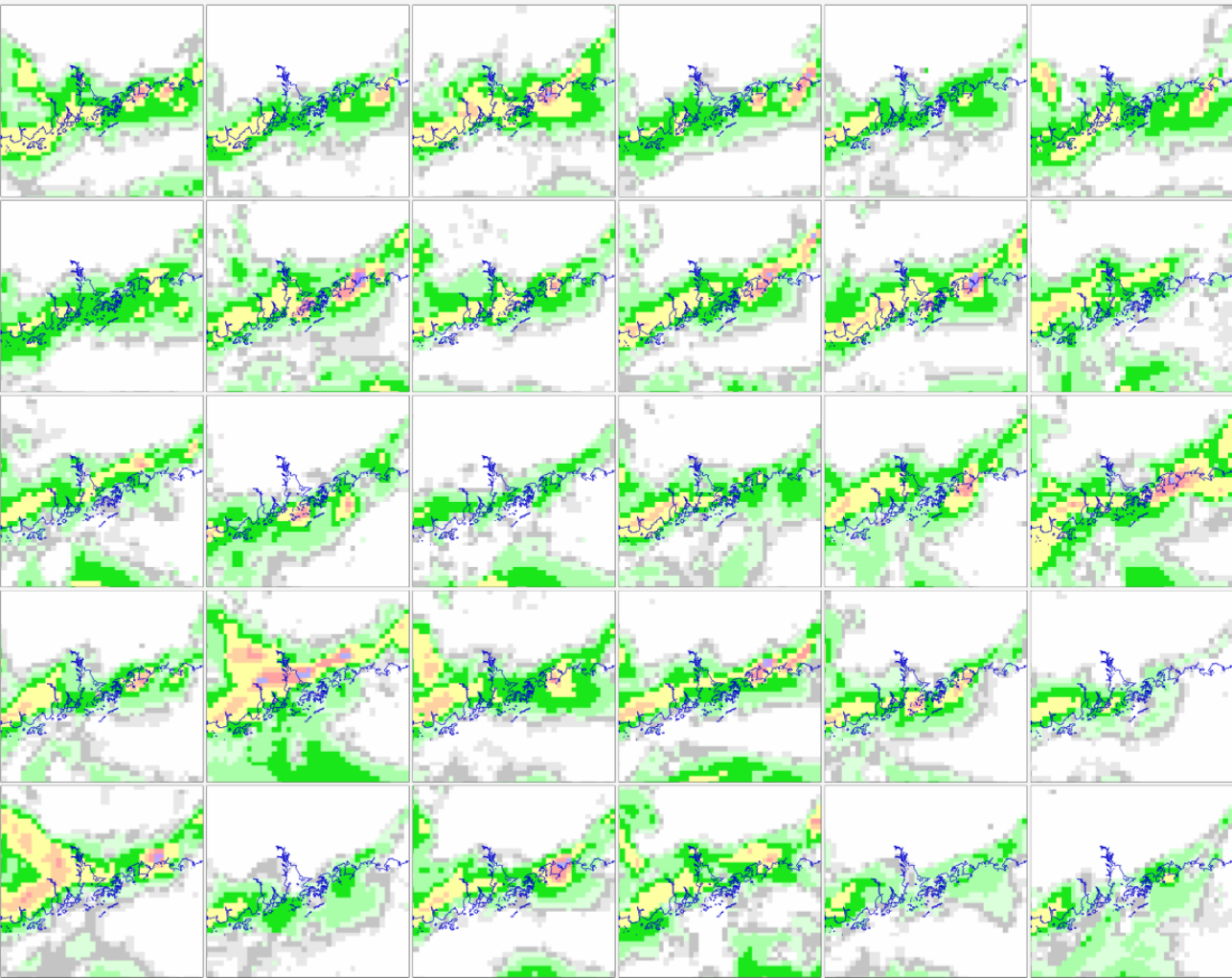
**E-W-oriented frontal rainband
First moving S'wards from
inland Guangdong**



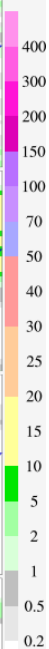
Black Rainstorm in Hong Kong (30 Sep 2020)



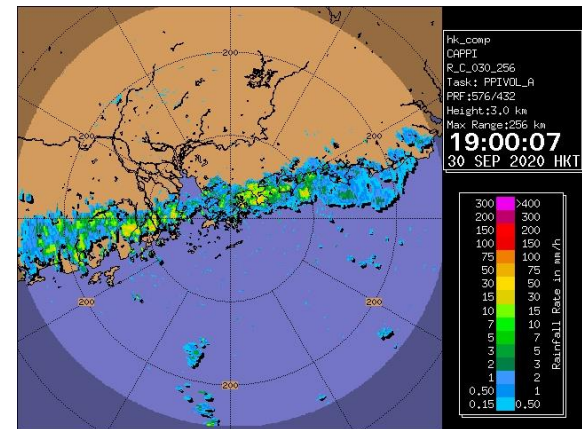
**E-W-oriented frontal rainband
First moving S'wards from
inland Guangdong**



mm

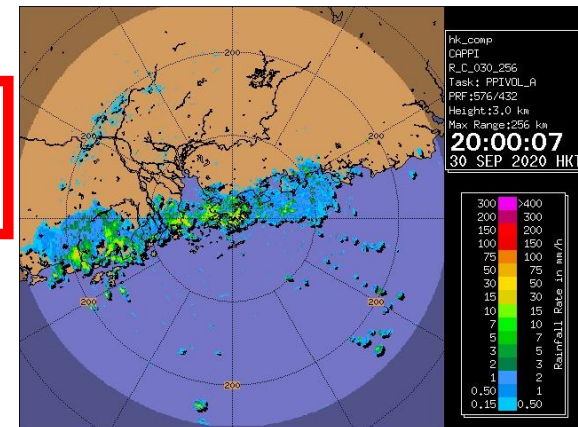
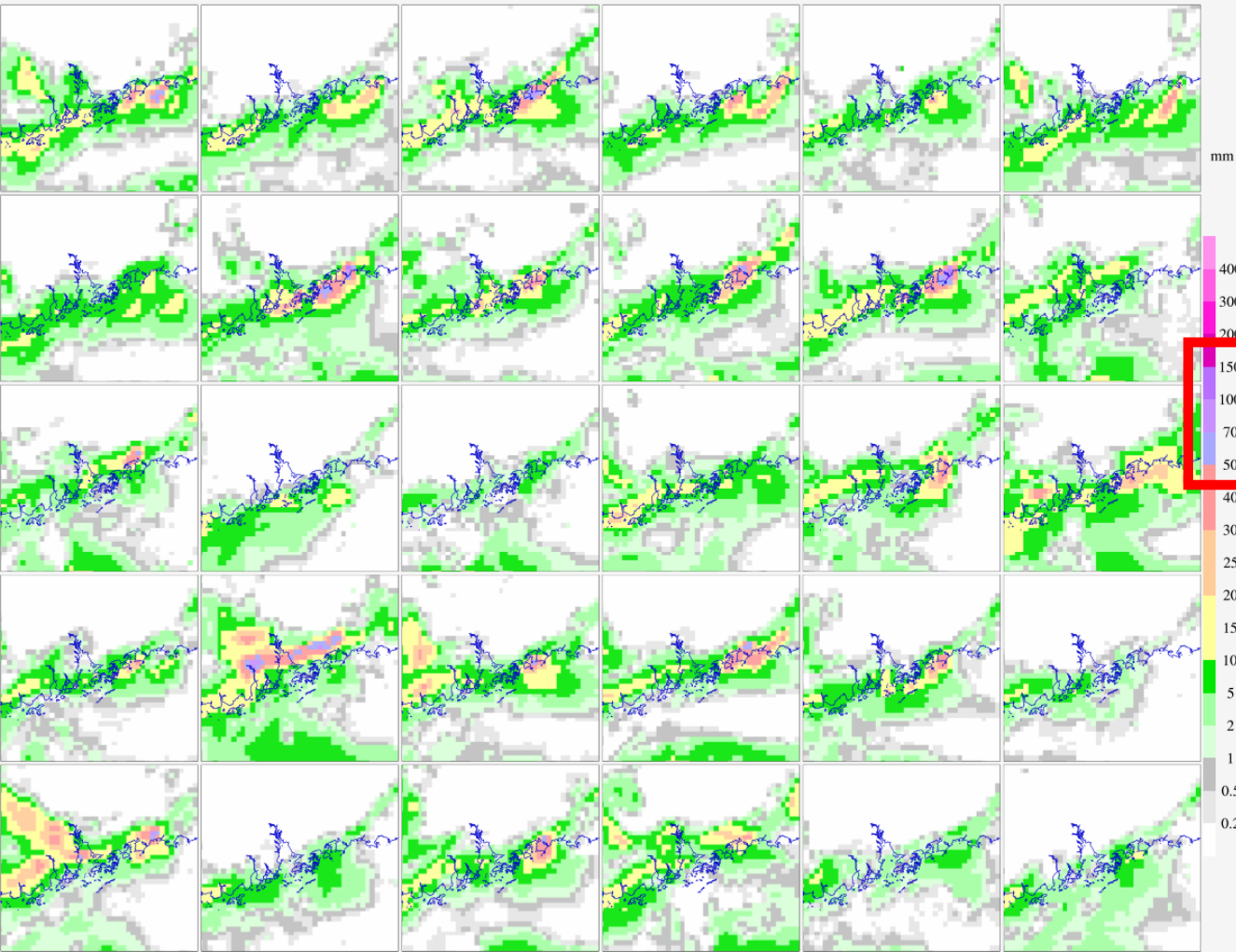


Black Rainstorm in Hong Kong (30 Sep 2020)

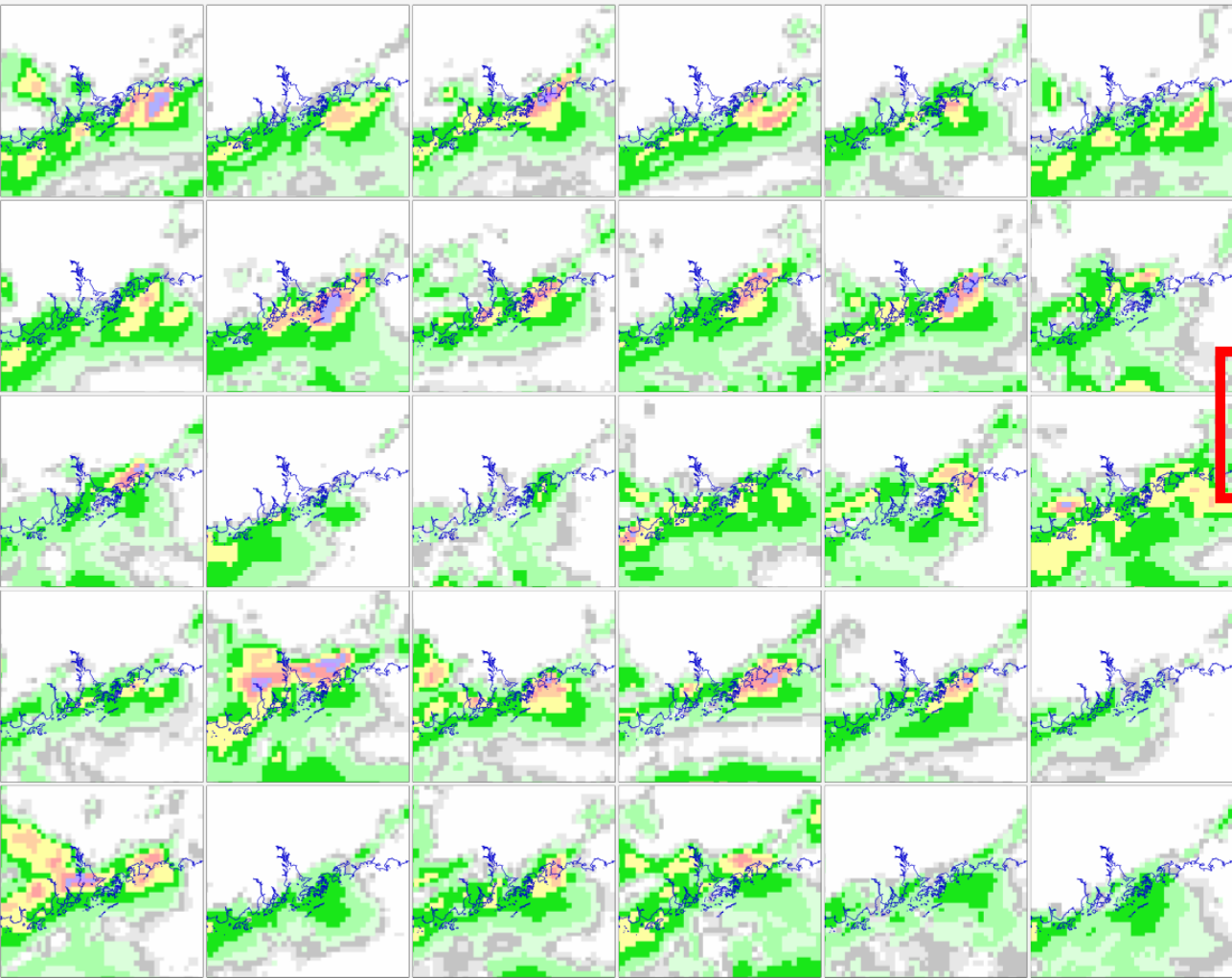


**Portion immediately N of HK
decayed in intensity
But another rain area just
E/NE of HK intensified...**

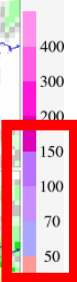
Black Rainstorm in Hong Kong (30 Sep 2020)



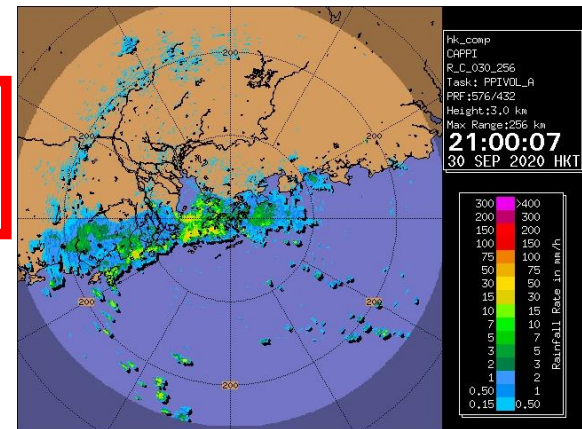
... and swept across most parts of Hong Kong, bringing hourly rainfall of 70 – 100 mm to many places (i.e. “Black”)



mm

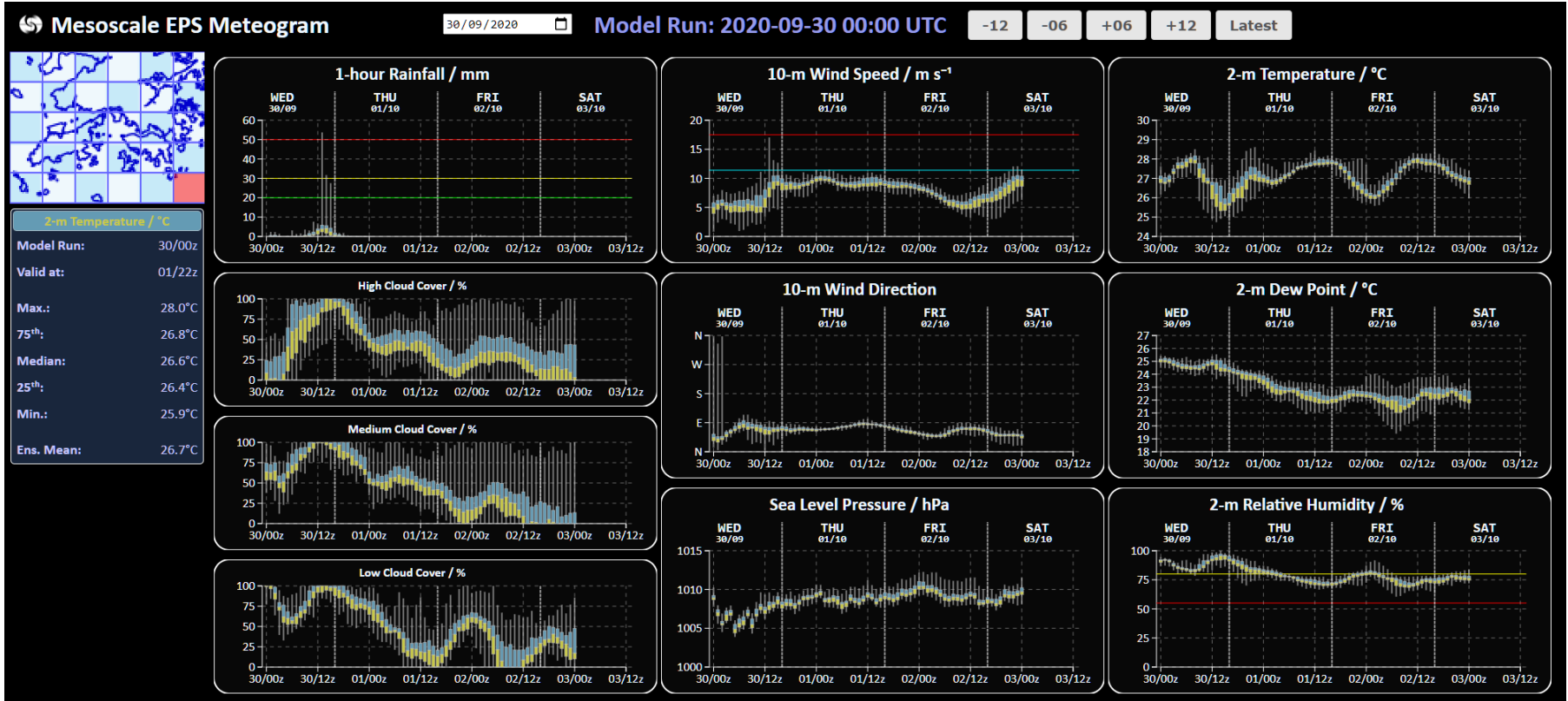


Black Rainstorm in Hong Kong (30 Sep 2020)

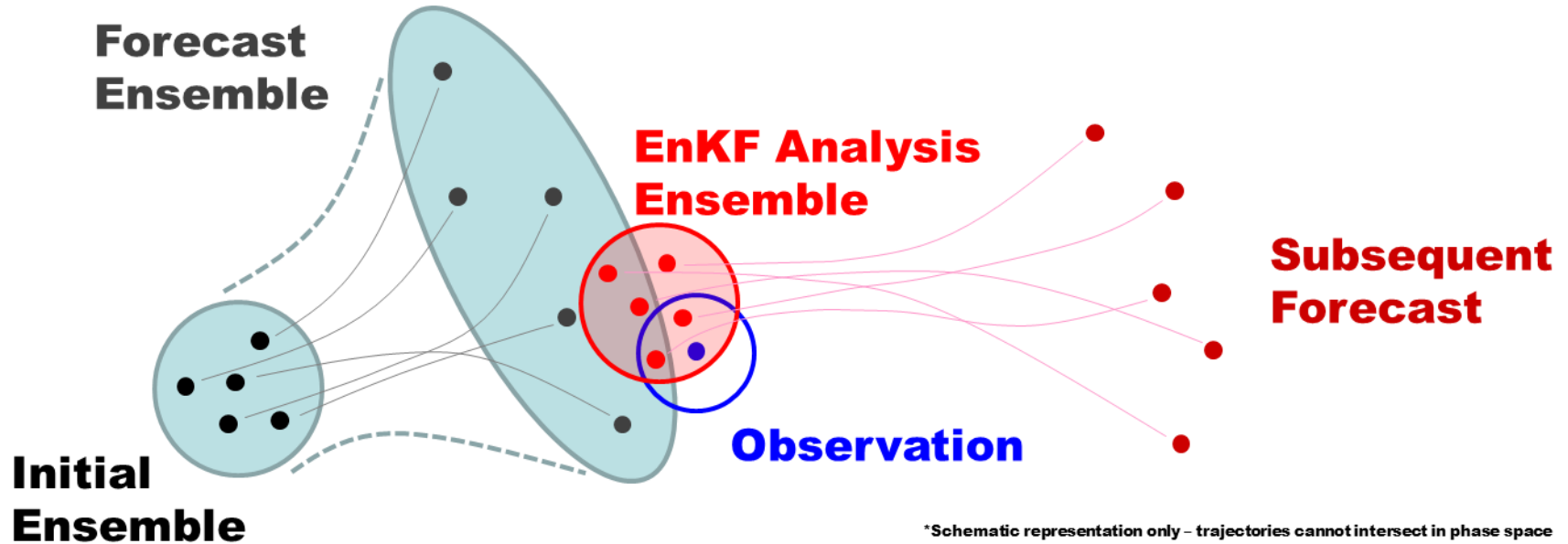


In this case the MEPS (just upgraded to 30 members) did a reasonably good job in the evolution & rain intensity

Visualisation of Mesoscale Ens. – Non-trivial!



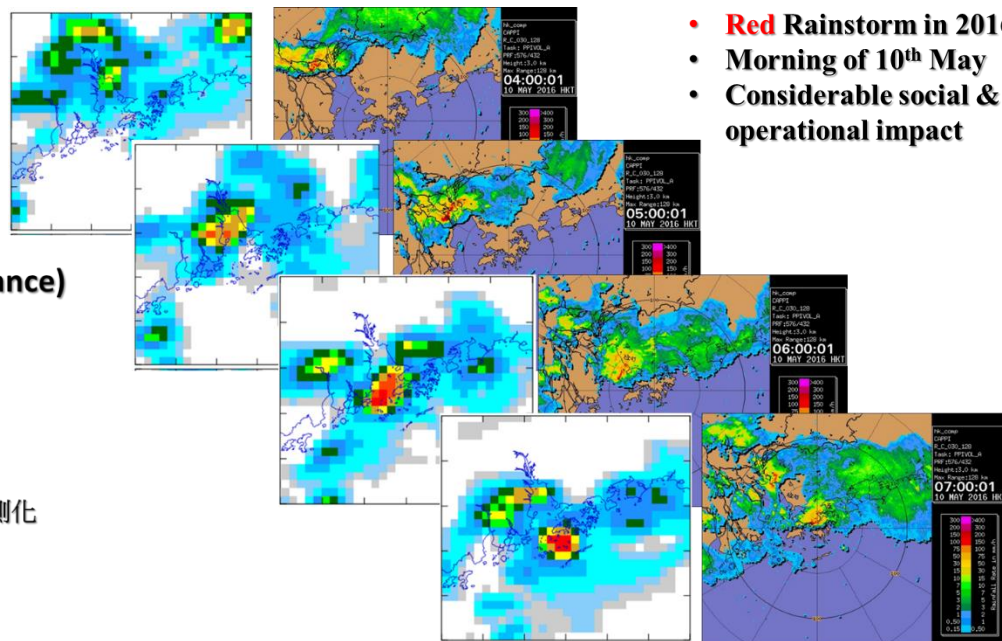
Experiments on Ensemble-based Assimilation



EnKF Assimilation of Radar Observations

$$K = P^f H^T (H P^f H^T + R)^{-1}$$

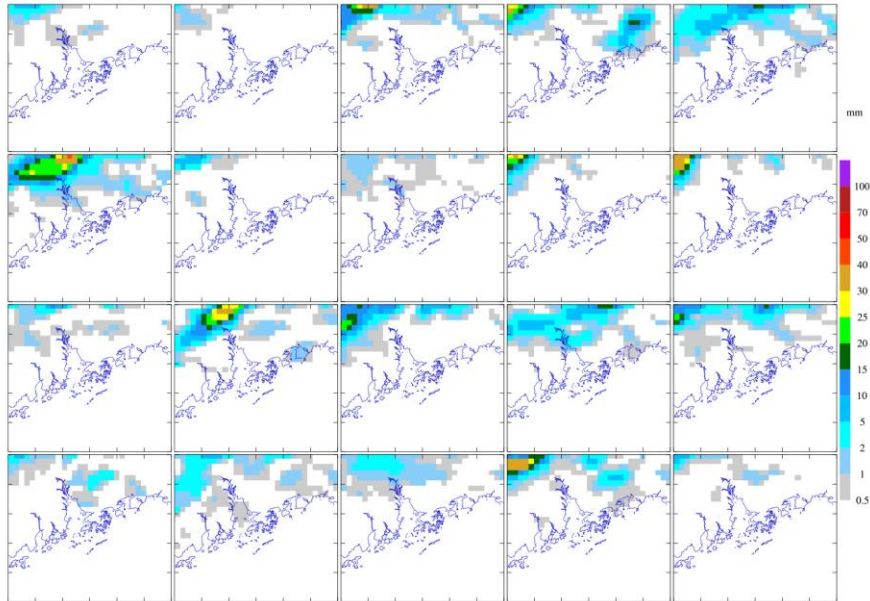
- **K** = 卡尔曼增益 (Kalman Gain)
- **P^f** = 背景误差协方差 (Background Error Covariance)
 - 以集合预报协方差作为背景误差协方差的近似
 - 从而在同化过程中引入流依赖特性
- **H** = 观测算子 (Observation Operator)
 - 非线性单偏振雷达反射率算子
 - 反射率 $Z_e = Z_{er} + Z_{es} + Z_{eg}$ 包括雨、雪、霰之混合比
 - 因应模式网格大小作出稀疏及配对，但不作超级观测化
- **R** = 观测误差协方差 (Observation Error)



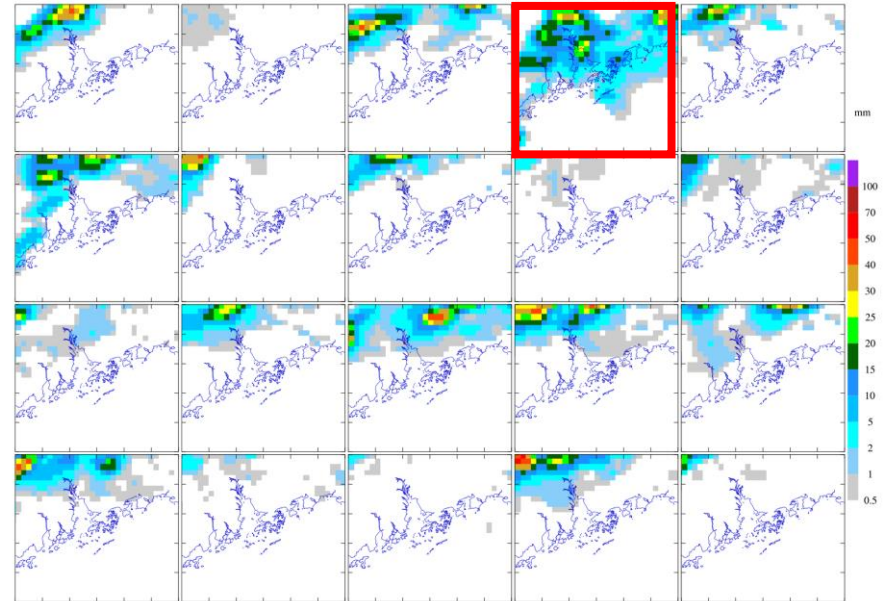
EnKF formulation following PennState Group

Experiments on Ensemble-based Assimilation

Experimental EPS
Rainfall Stamp Map (1-hour RF) ~~MON 2016-05-09 20:00 UTC~~ **MON 2016-05-09 20:00 UTC**
1-hour RF
~ Control Run ~
Initialised at (UTC):
2016-05-09 12:00



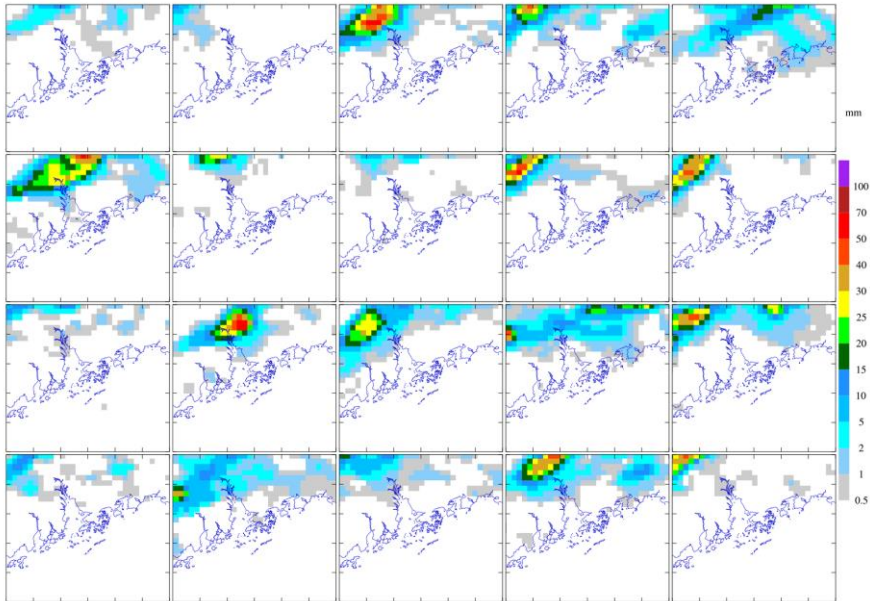
Experimental EPS
Rainfall Stamp Map (1-hour RF) ~~MON 2016-05-09 20:00 UTC~~ **MON 2016-05-09 20:00 UTC**
1-hour RF
~ EnKF Run ~
Initialised at (UTC):
2016-05-09 12:00



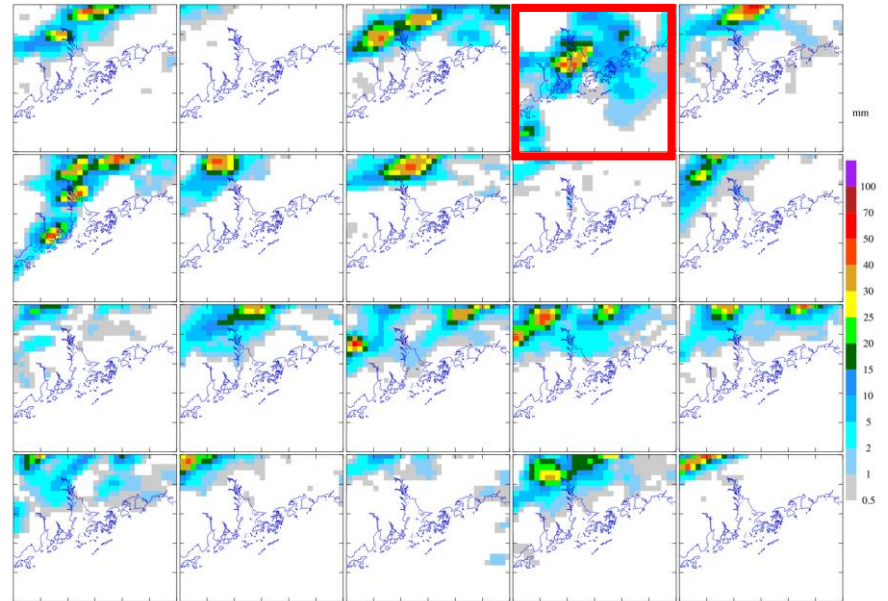
A very complex rainstorm episode with little predictability even within T+12

Experiments on Ensemble-based Assimilation

Experimental EPS
Rainfall Stamp Map (3-hour RF) ~~MON 2016-05-09 21:00 UTC~~
1-hour RF
Initialised at (UTC):
2016-05-09 12:00
~ Control Run ~



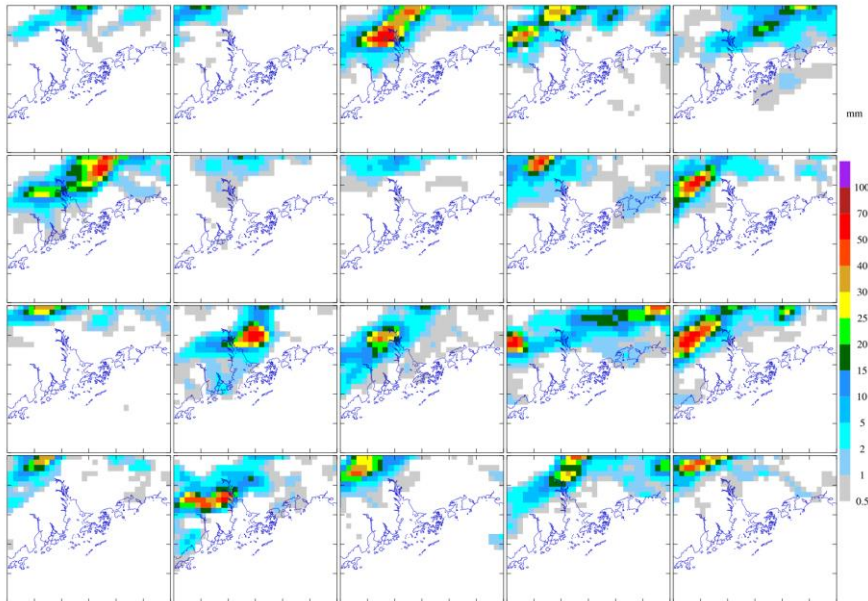
Experimental EPS
Rainfall Stamp Map (3-hour RF) ~~MON 2016-05-09 21:00 UTC~~
1-hour RF
Initialised at (UTC):
2016-05-09 12:00
~ EnKF Run ~



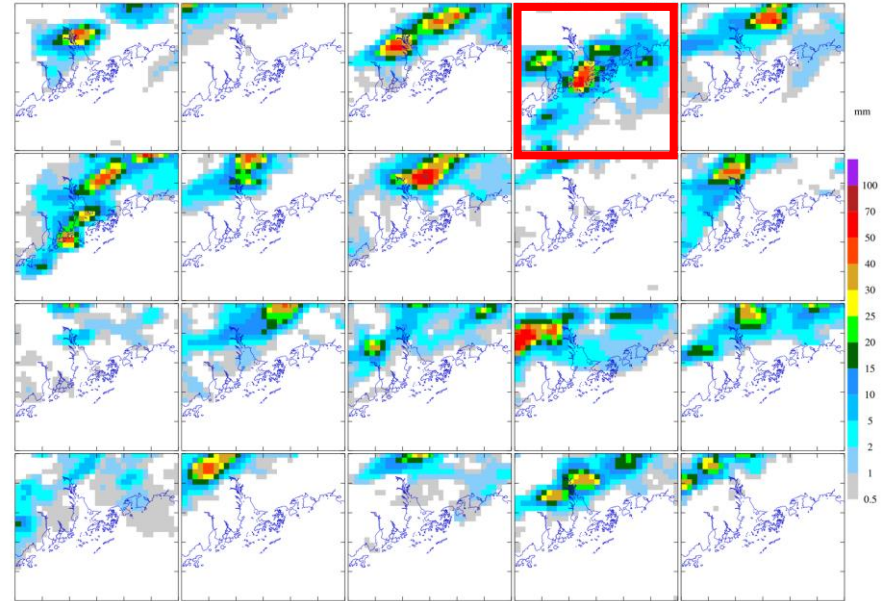
A very complex rainstorm episode with little predictability even within T+12

Experiments on Ensemble-based Assimilation

Experimental EPS
Rainfall Stamp Map (1-hour RF) ~~MON 2016-05-09 22:00 UTC~~
1-hour RF
~ Control Run ~
Initialised at (UTC):
2016-05-09 12:00



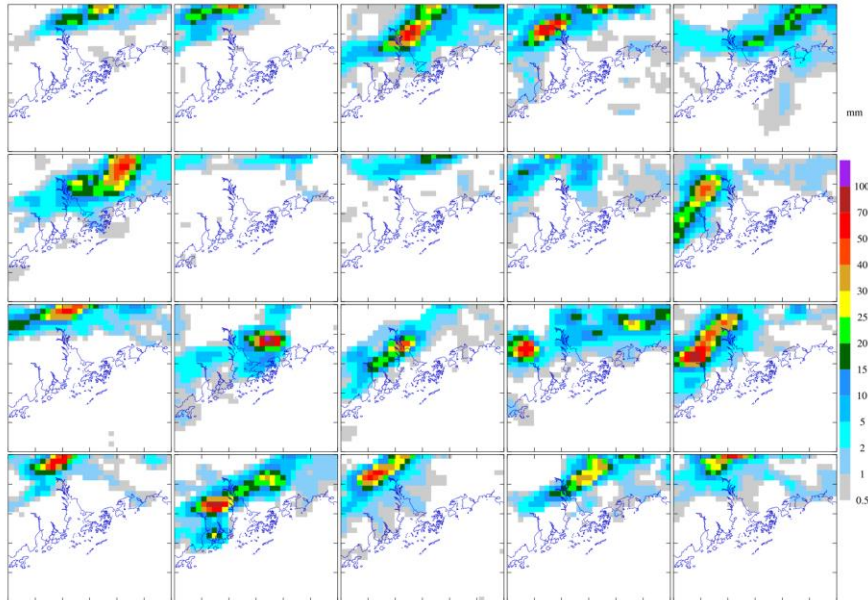
Experimental EPS
Rainfall Stamp Map (1-hour RF) ~~MON 2016-05-09 22:00 UTC~~
1-hour RF
~ EnKF Run ~
Initialised at (UTC):
2016-05-09 12:00



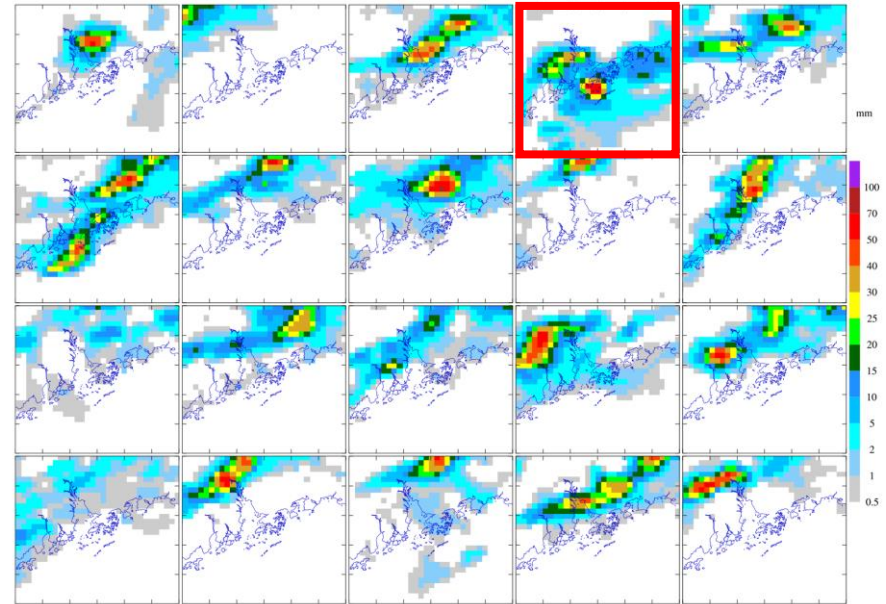
A very complex rainstorm episode with little predictability even within T+12

Experiments on Ensemble-based Assimilation

Experimental EPS
Rainfall Stamp Map (~~3-hour RF~~)
1-hour RF **MON 2016-05-09 23:00 UTC** Initialised at (UTC):
2016-05-09 12:00
~ Control Run ~

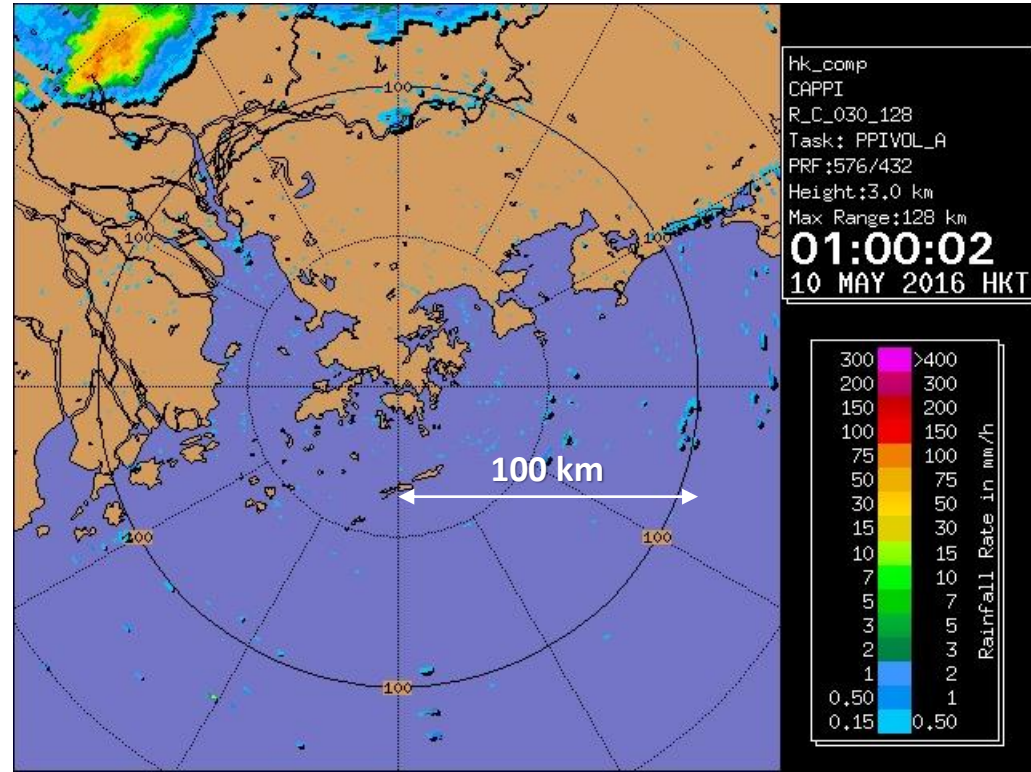
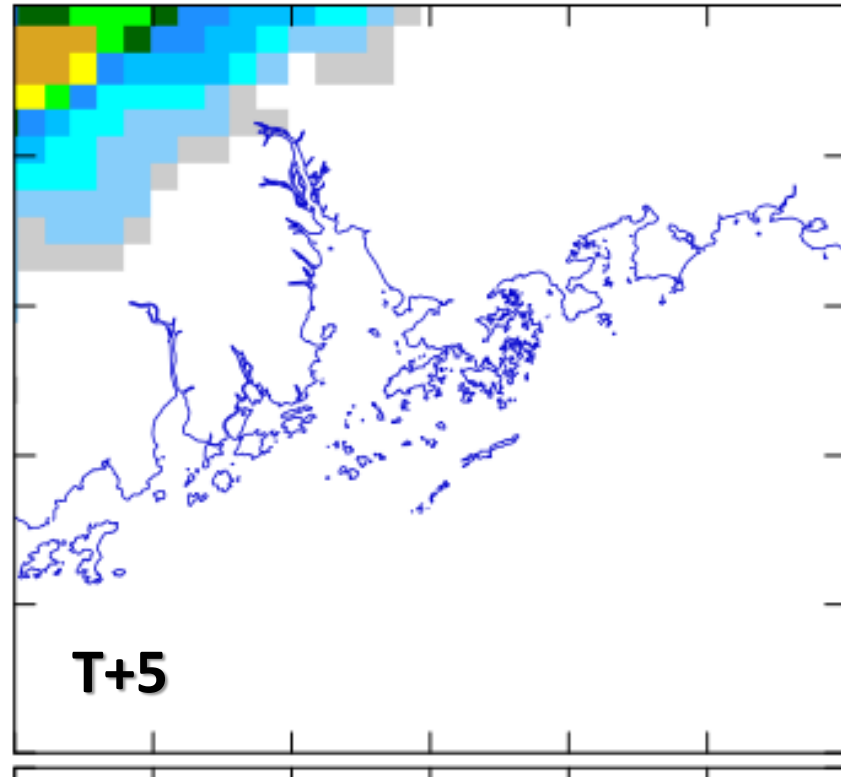


Experimental EPS
Rainfall Stamp Map (~~3-hour RF~~)
1-hour RF **MON 2016-05-09 23:00 UTC** Initialised at (UTC):
2016-05-09 12:00
~ EnKF Run ~

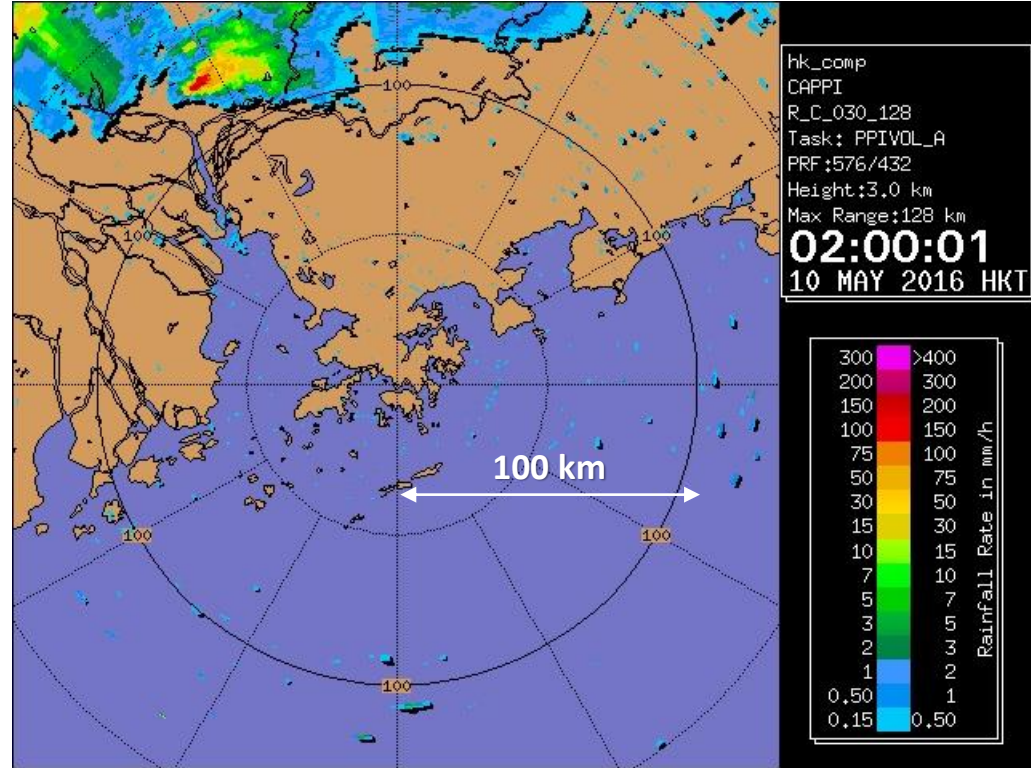
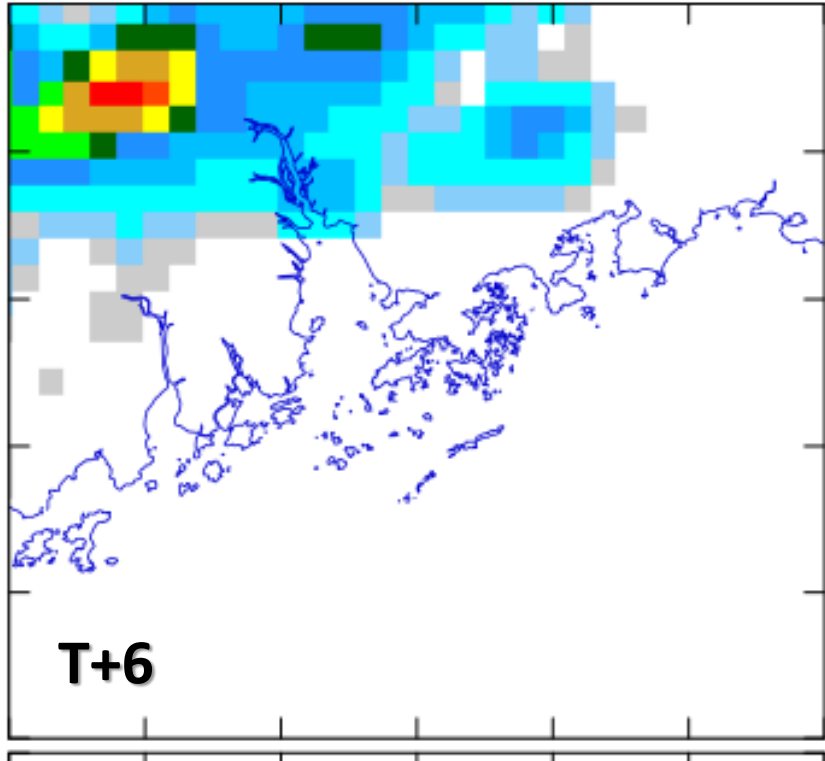


A very complex rainstorm episode with little predictability even within T+12

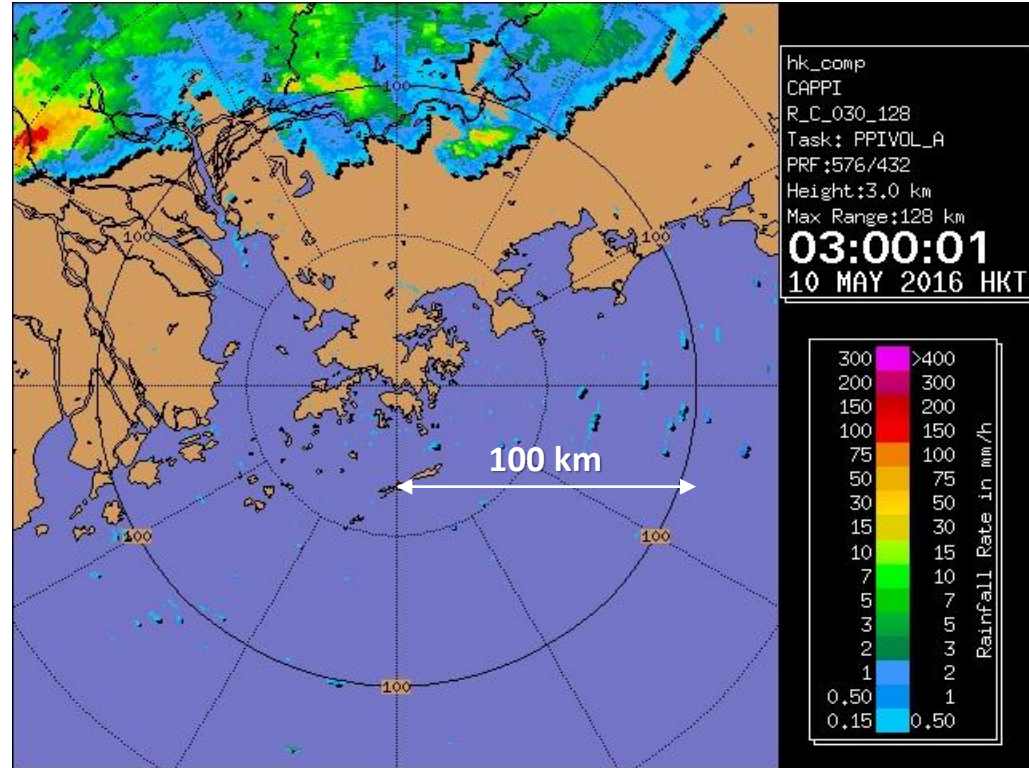
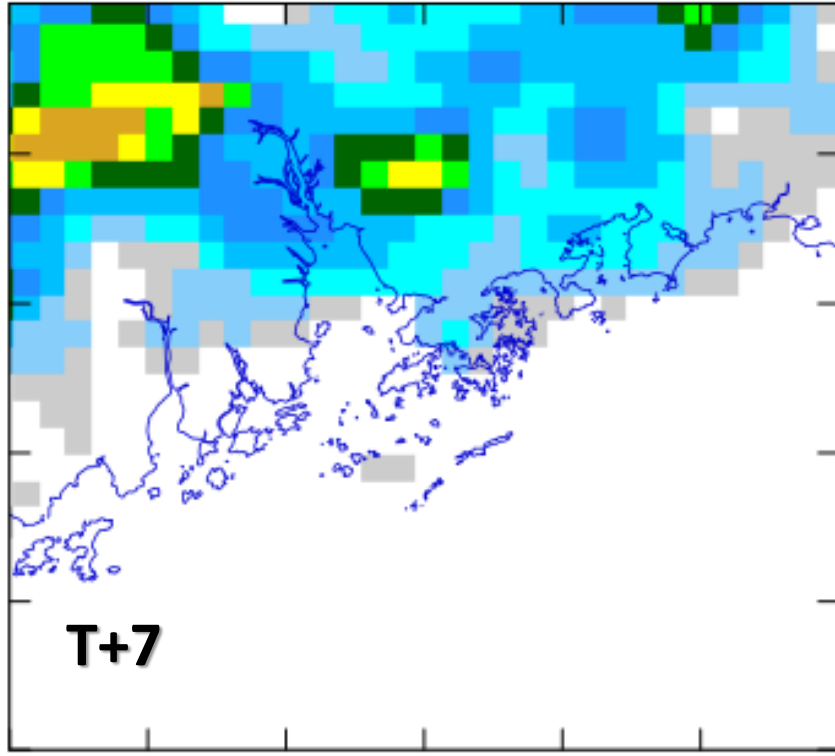
Best Member after EnKF Radar DA



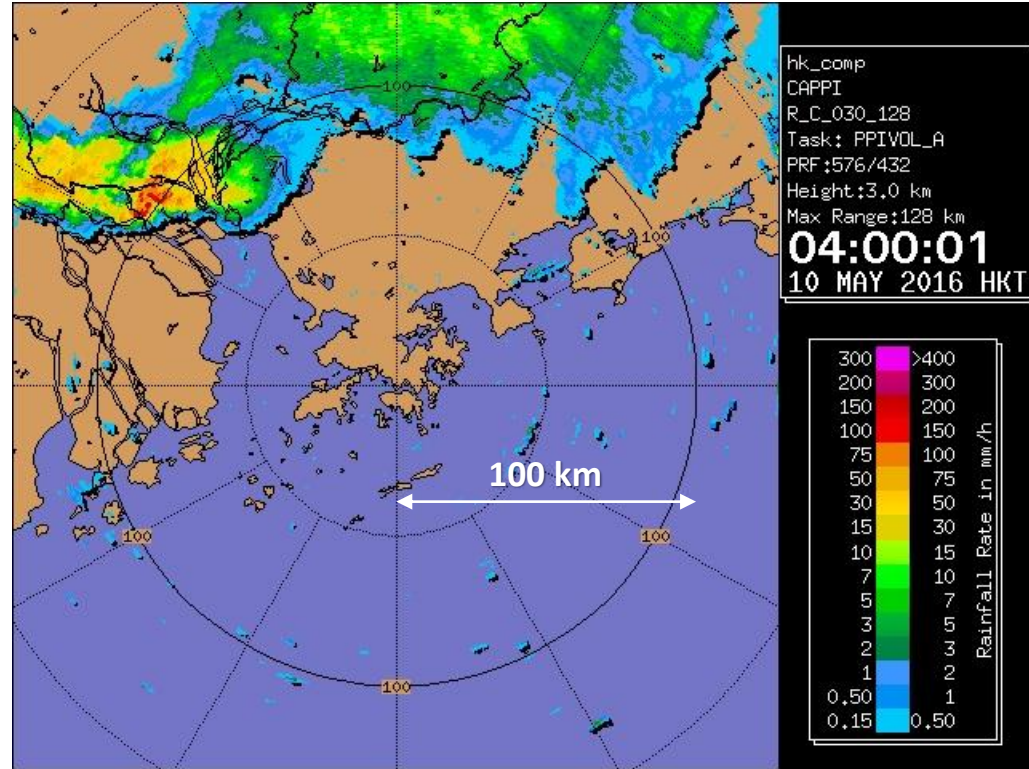
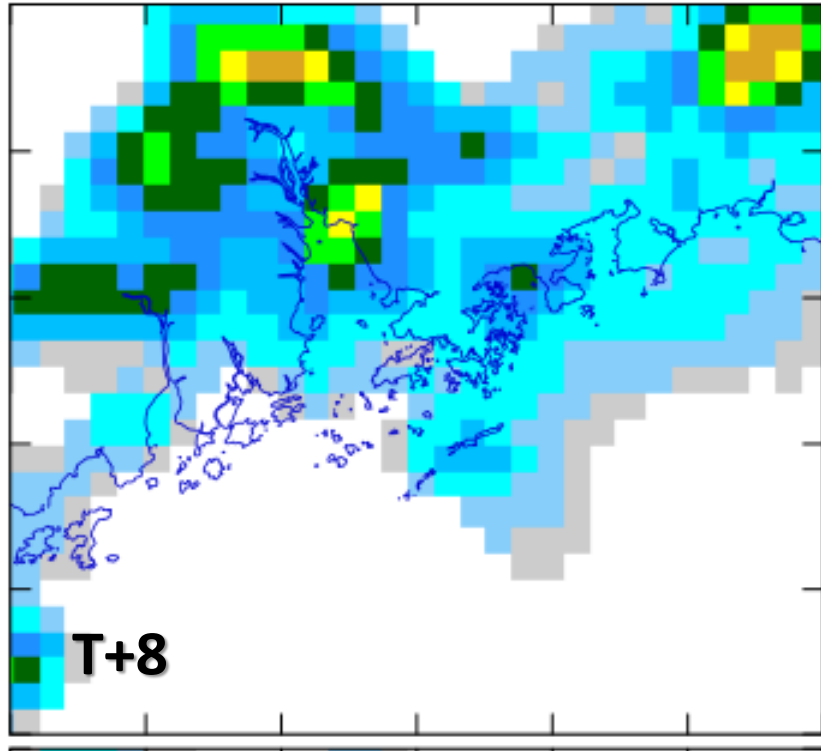
Best Member after EnKF Radar DA



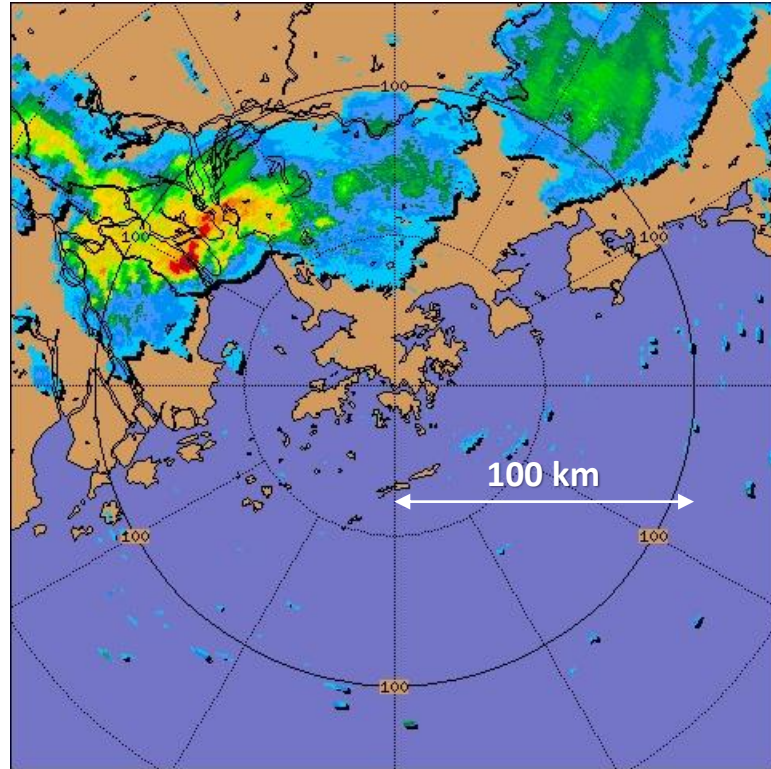
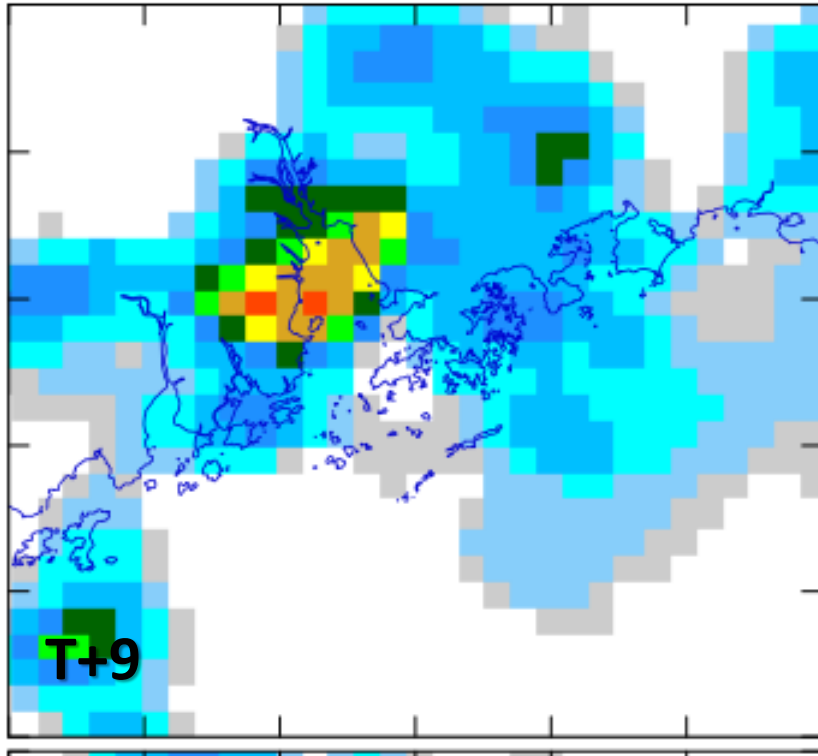
Best Member after EnKF Radar DA



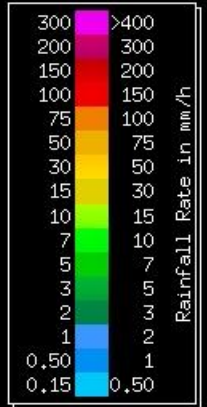
Best Member after EnKF Radar DA



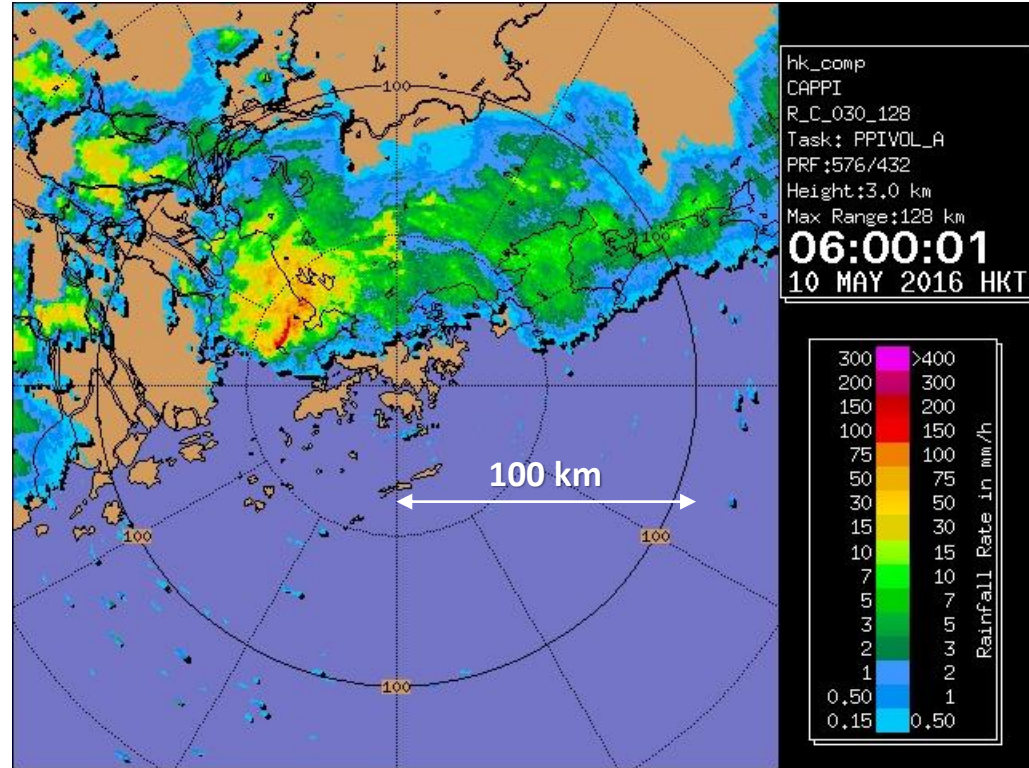
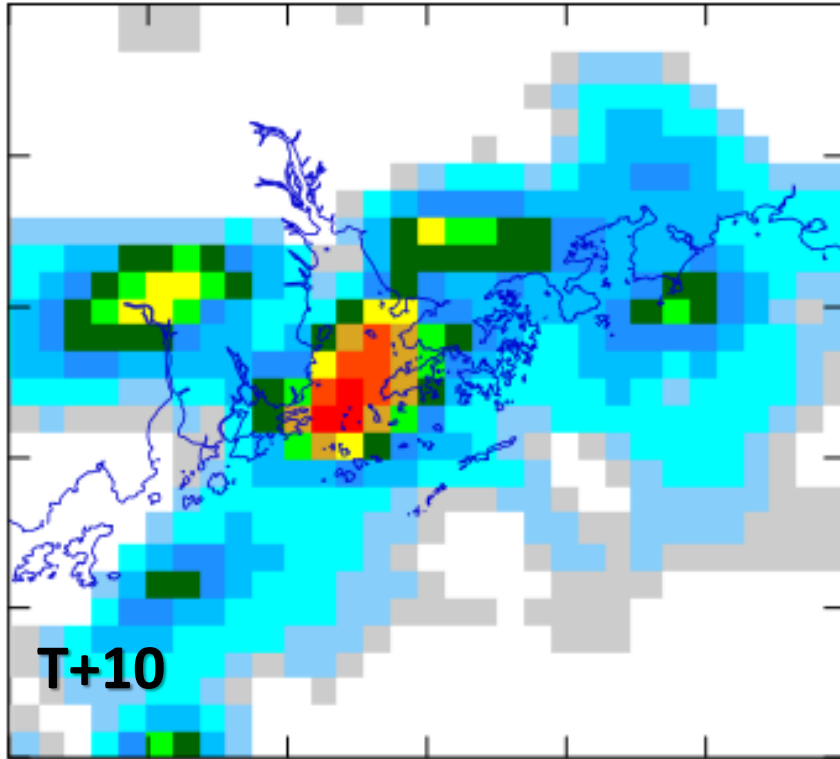
Best Member after EnKF Radar DA



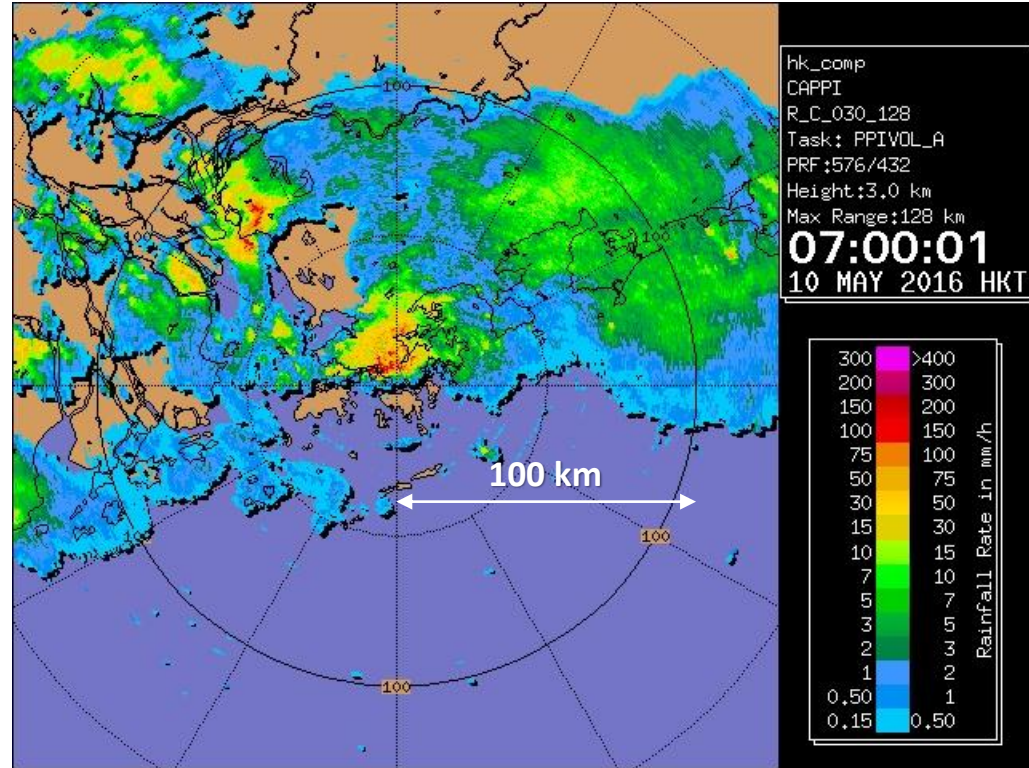
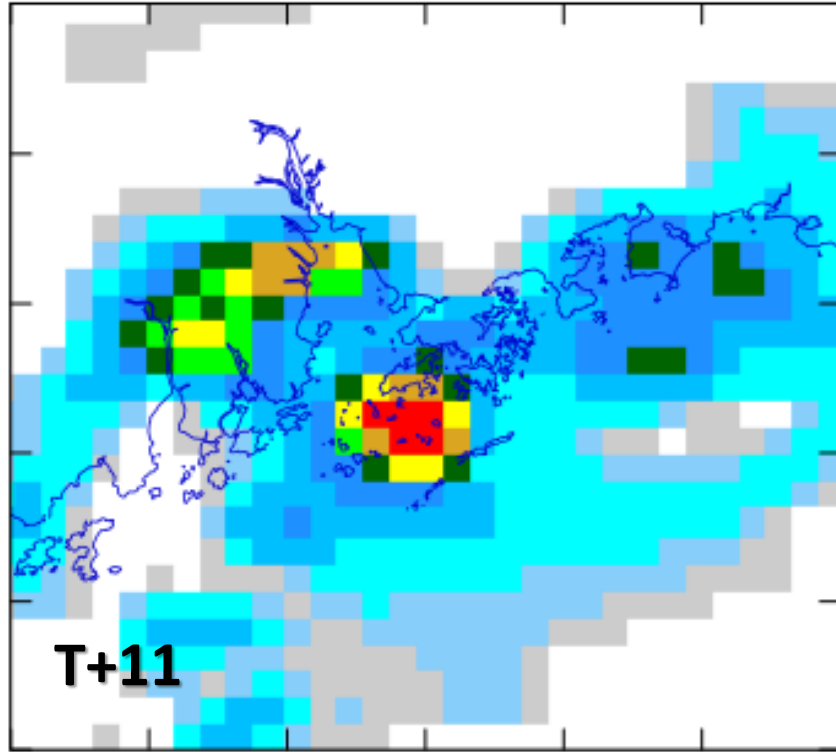
hk_comp
CAPPI
R_C_030_128
Task: PPIVOL_A
PRF:576/432
Height:3.0 km
Max Range:128 km
05:00:01
10 MAY 2016 HKT



Best Member after EnKF Radar DA

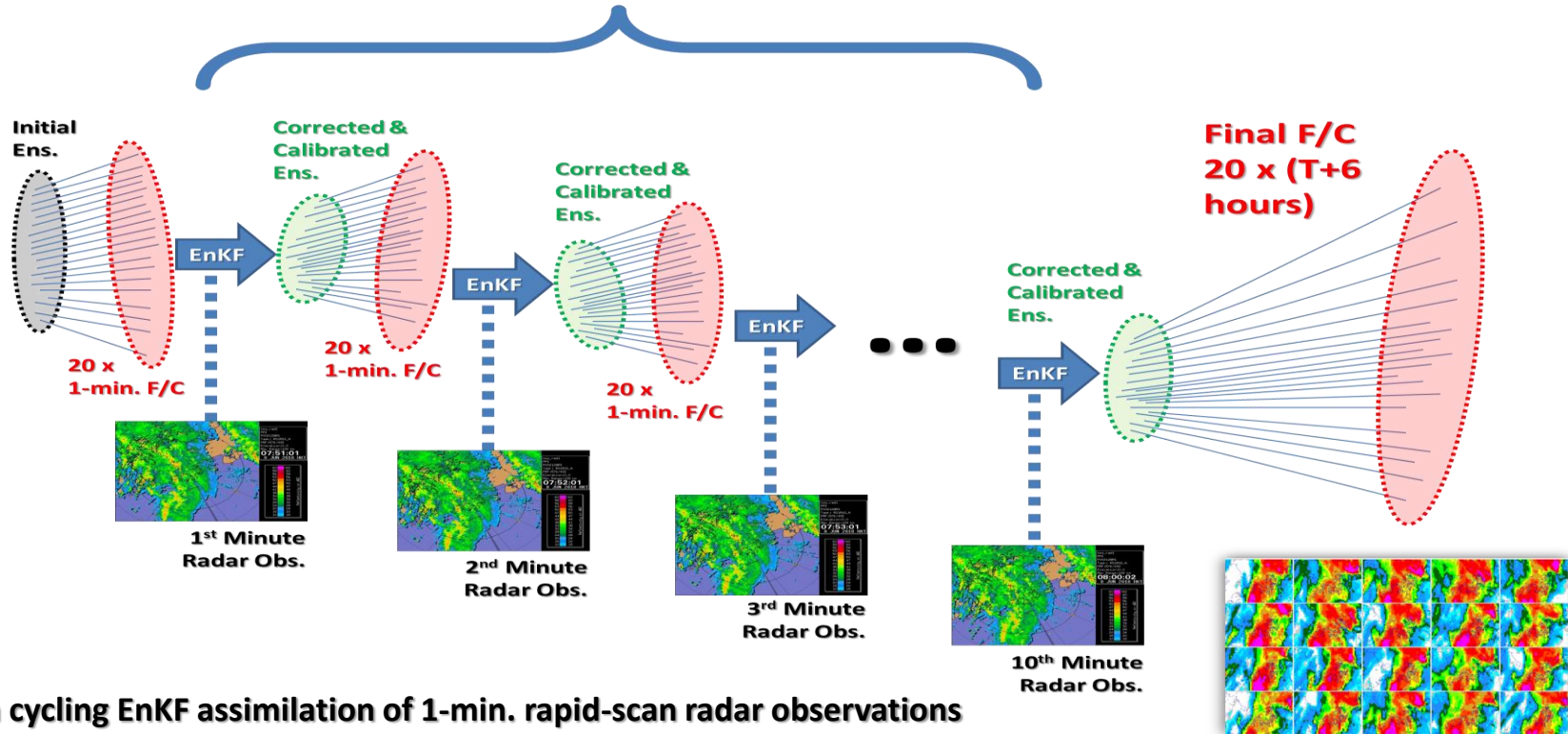


Best Member after EnKF Radar DA



Synergy between NWP & Hardware Teams

10 x (EnKF + Ens. Forecast) @ 1-min. Intervals



Closing Remarks & Looking Ahead

- **Rapidly advancing NWP, DA & HPC capabilities**
- **Still remains considerable scientific challenges**
- **NWP developers constantly facing uphill battles**
 - **Major global models approaching convective res.**
 - **User demands for ever-increasing “accuracy”**
 - **Manpower & funding in post-COVID world**
- **Regional/in-house NWP needs to “prove its worth”**
- **We try to do the best we can – surely you too!**

~ Questions & Comments ~

kkhon@hko.gov.hk