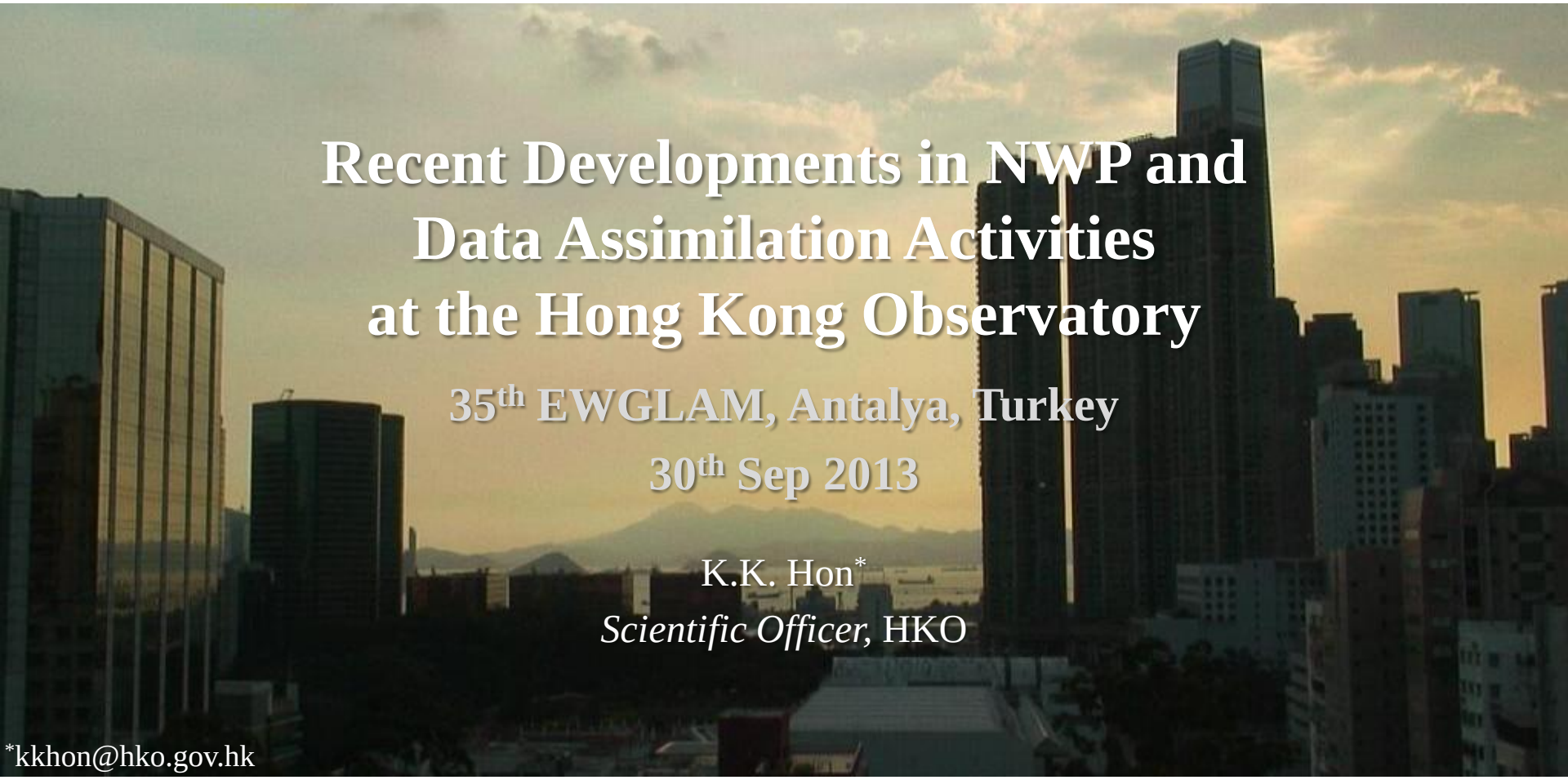


Recent Developments in NWP and Data Assimilation Activities at the Hong Kong Observatory

35th EWGLAM, Antalya, Turkey

30th Sep 2013

K.K. Hon*

Scientific Officer, HKO

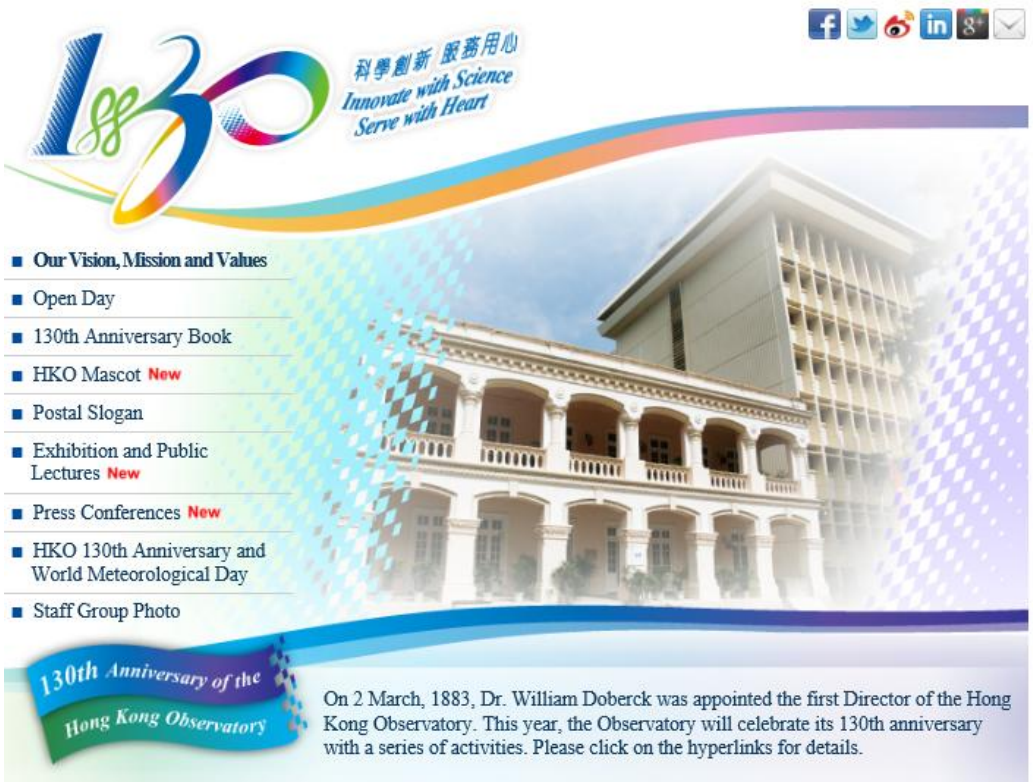
*kkhon@hko.gov.hk

香港天文台
HONG KONG OBSERVATORY

The *Hong Kong Observatory*

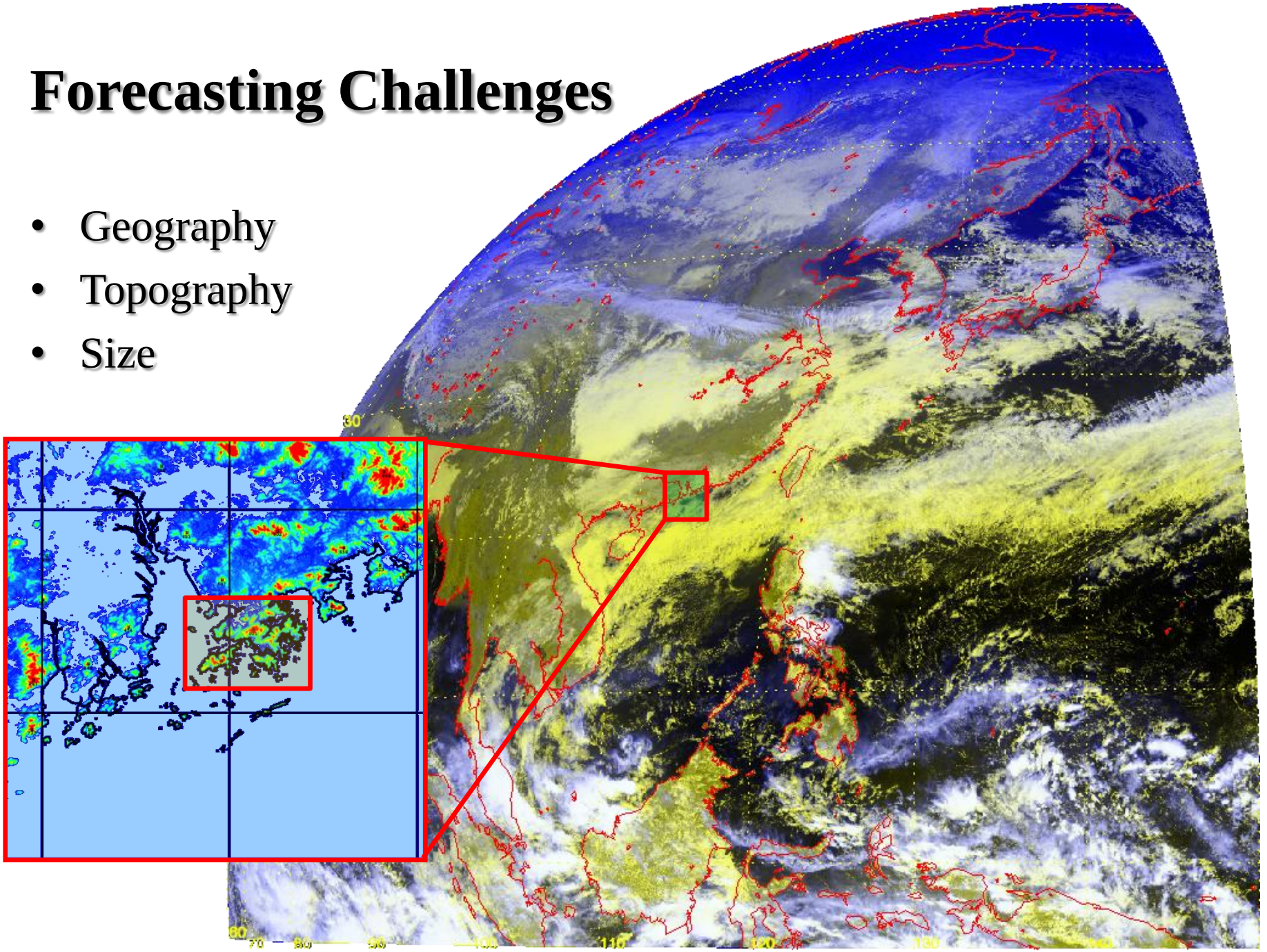
香港天文台
HONG KONG OBSERVATORY

- Department of the Government of the Hong Kong Special Administrative Region, People's Republic of China
- 4 Branches:
  - **F***orecasting and Warning Services*
  - **A***viation Weather Services*
  - **D***evelopment, Research and Administration*
  - **R***adiation Monitoring and Assessment*
- Founded in 1883
  - 130th Anniversary

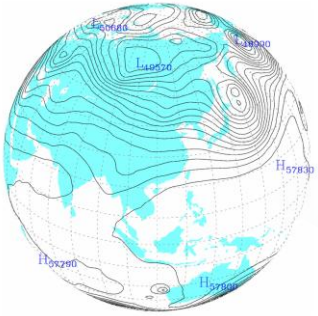


Forecasting Challenges

- Geography
- Topography
- Size

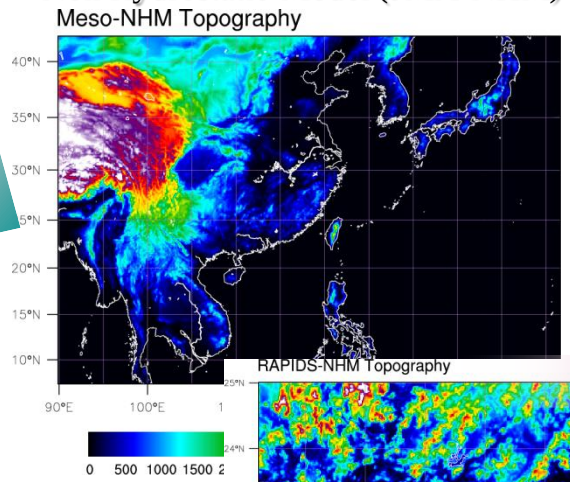


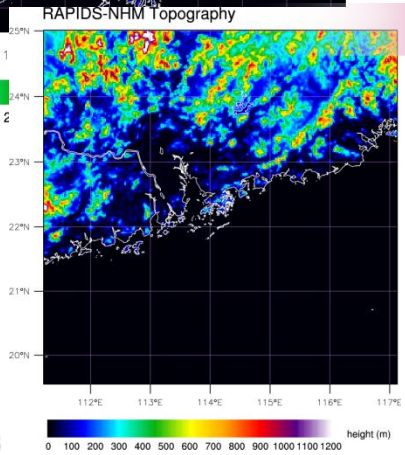
Atmospheric Integrated Rapid-cycle (AIR) Forecast Model System

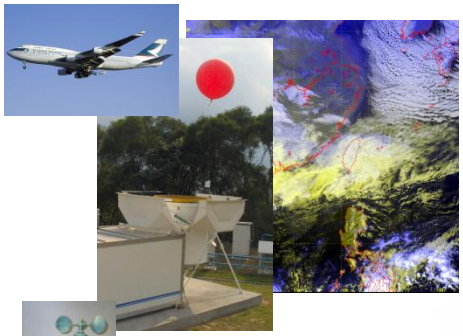


Boundary conditions from
ECMWF IFS / JMA-GSM

Two regional domains of the
Non Hydrostatic Model (JMA-NHM)





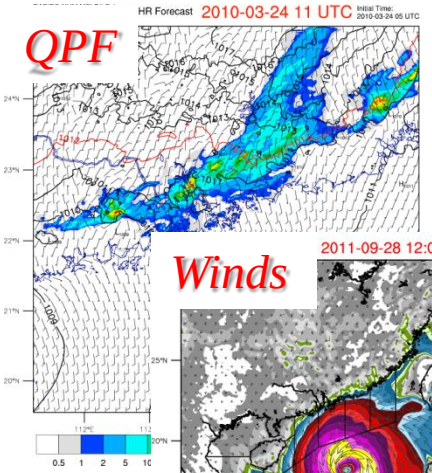


JNoVA-3DVAR

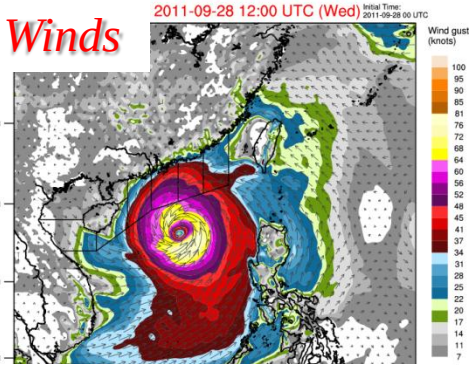
Meteorological Observations

Conventional
Automatic weather stations (HK and Guangdong)
Aircraft (AMDAR)
Satellite - cloud motion wind, temperature retrieved profiles, PWV
Tropical cyclone bogus data
GPS -PWV
Radar – Doppler Velocity, 3-D wind retrieval & Reflectivity
Aircraft Reconnaissance Data (GFS)

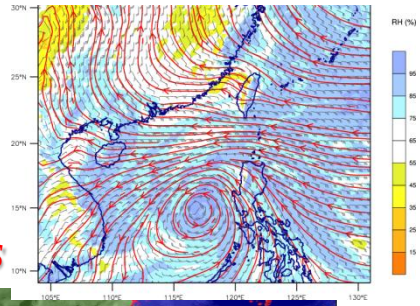
QPF



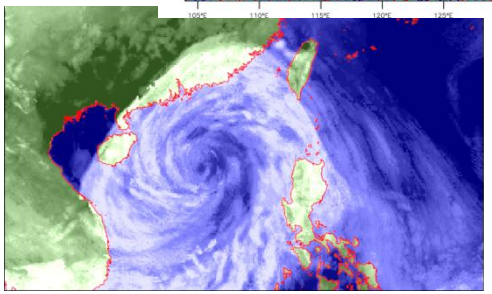
Winds



Temperature and relative humidity

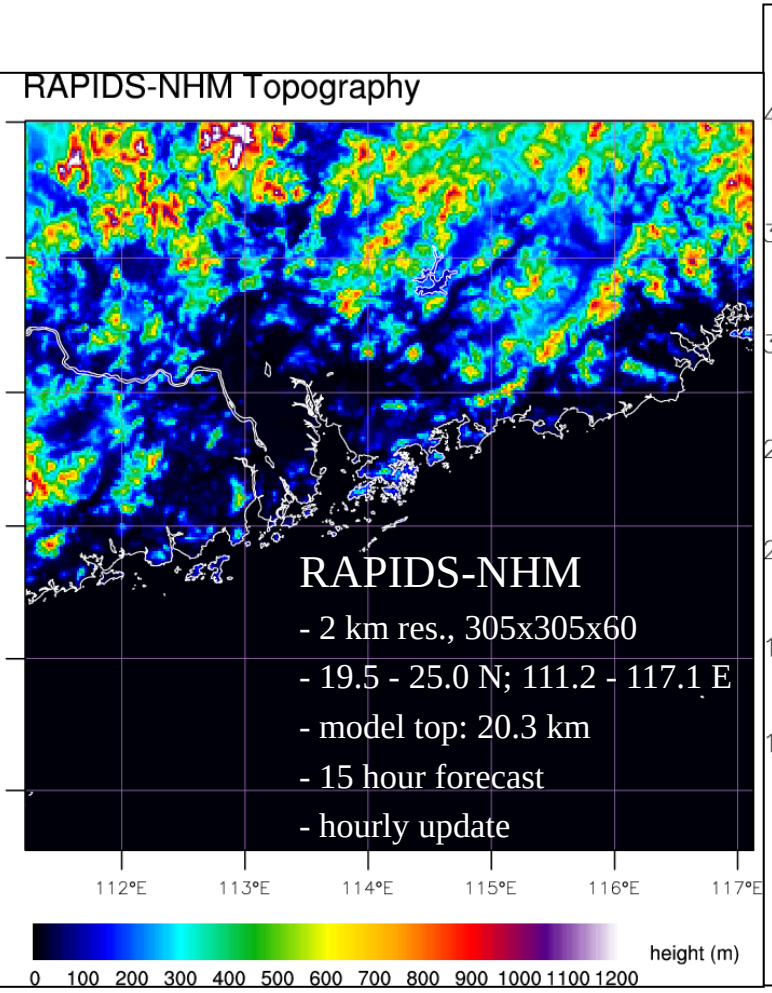


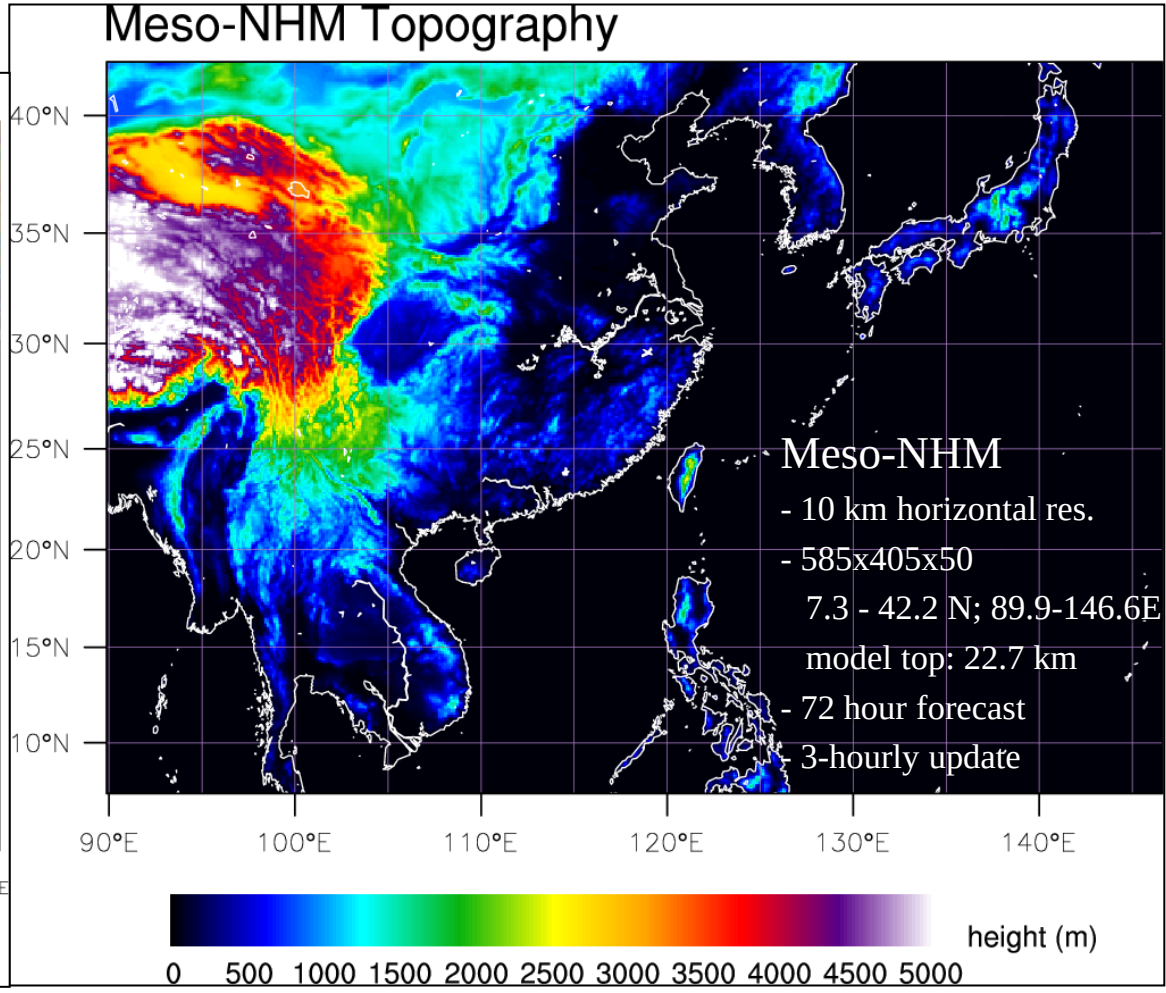
Cloudiness



Meso-NHM and RAPIDS-NHM in AIR Forecast Model System

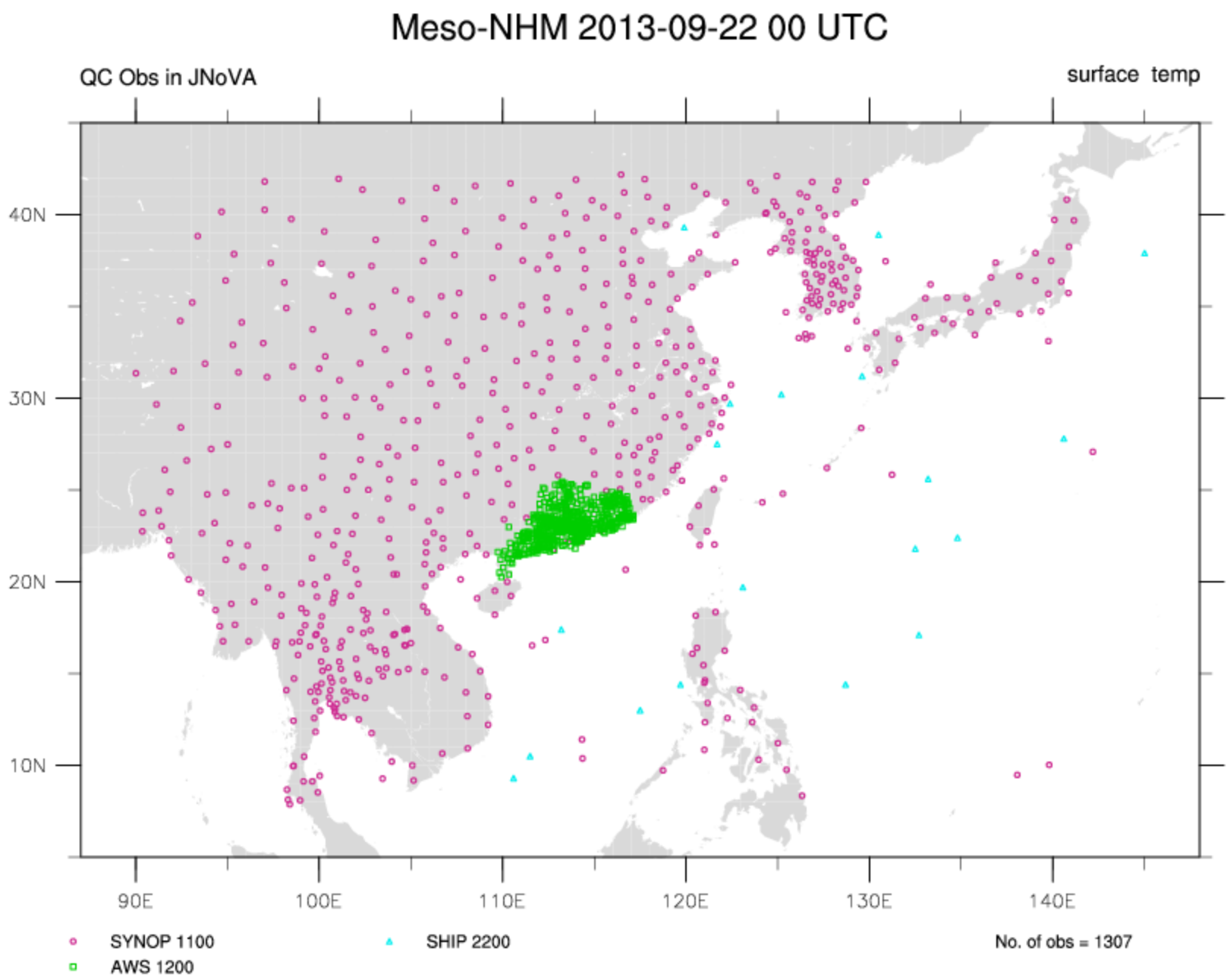
- Meso-NHM – Short Range (0-72 h) Mesoscale Prediction
- RAPIDS-NHM – Storm-scale Prediction (0-15h), QPF input to RAPIDS to blend with SWIRLS nowcast

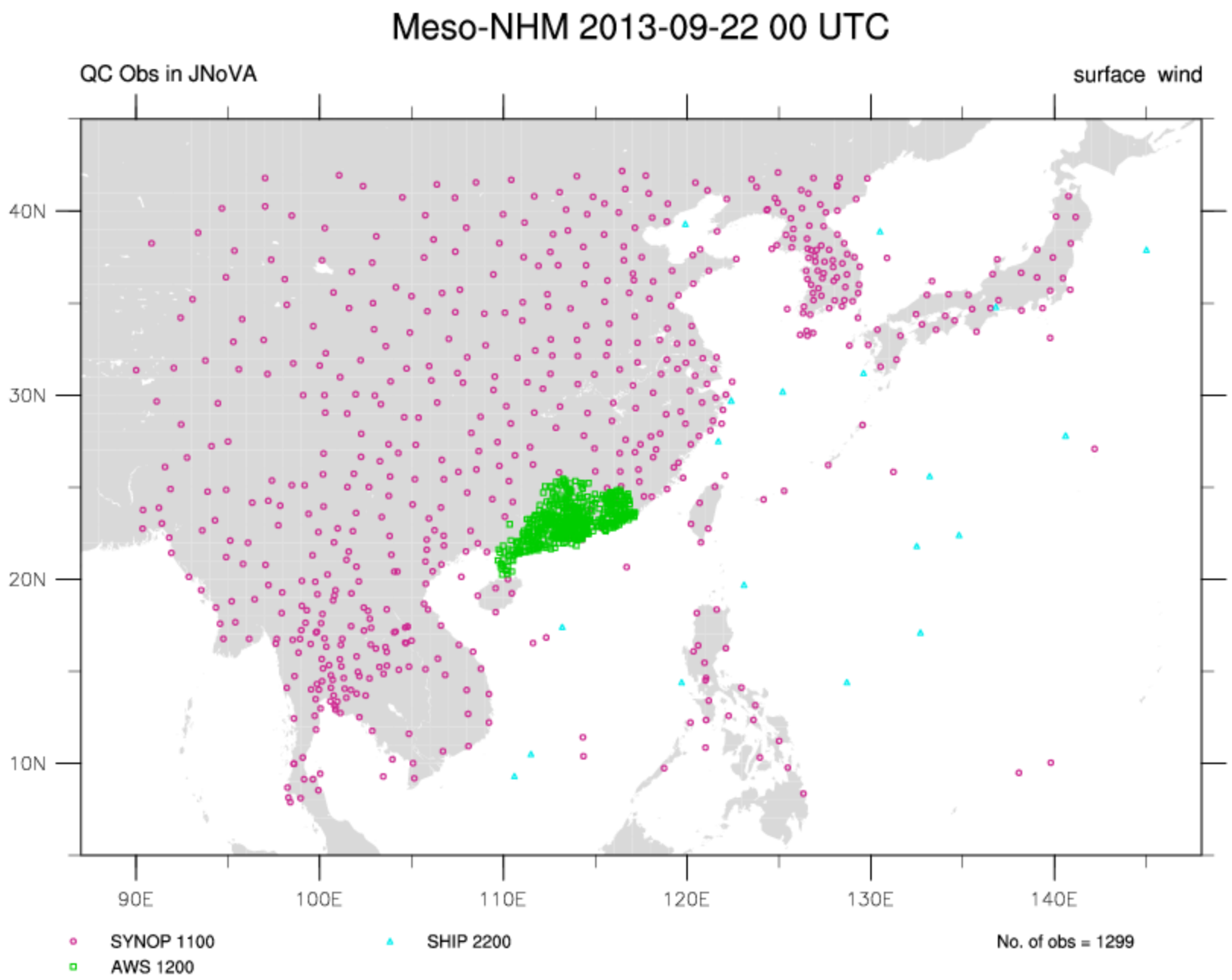


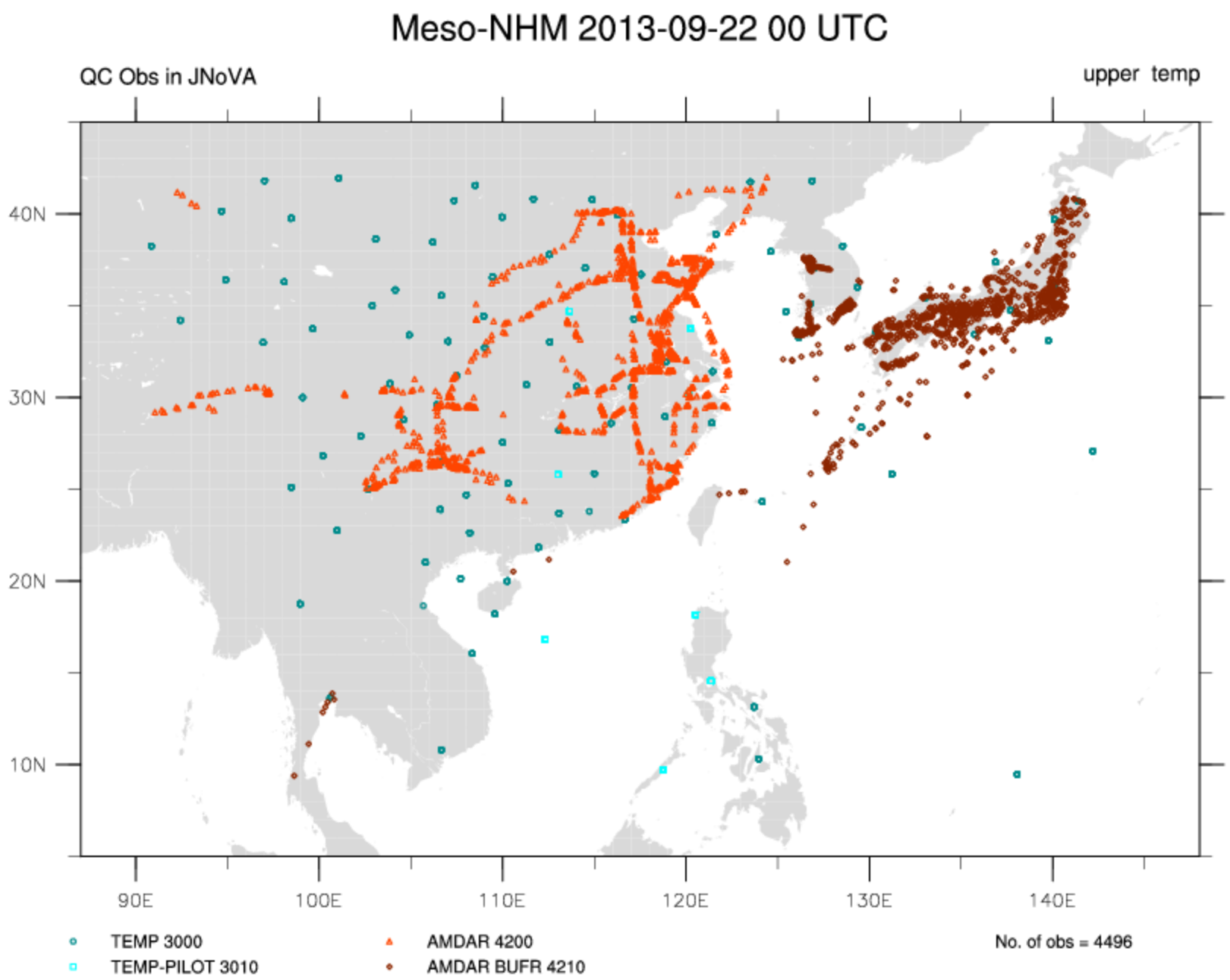


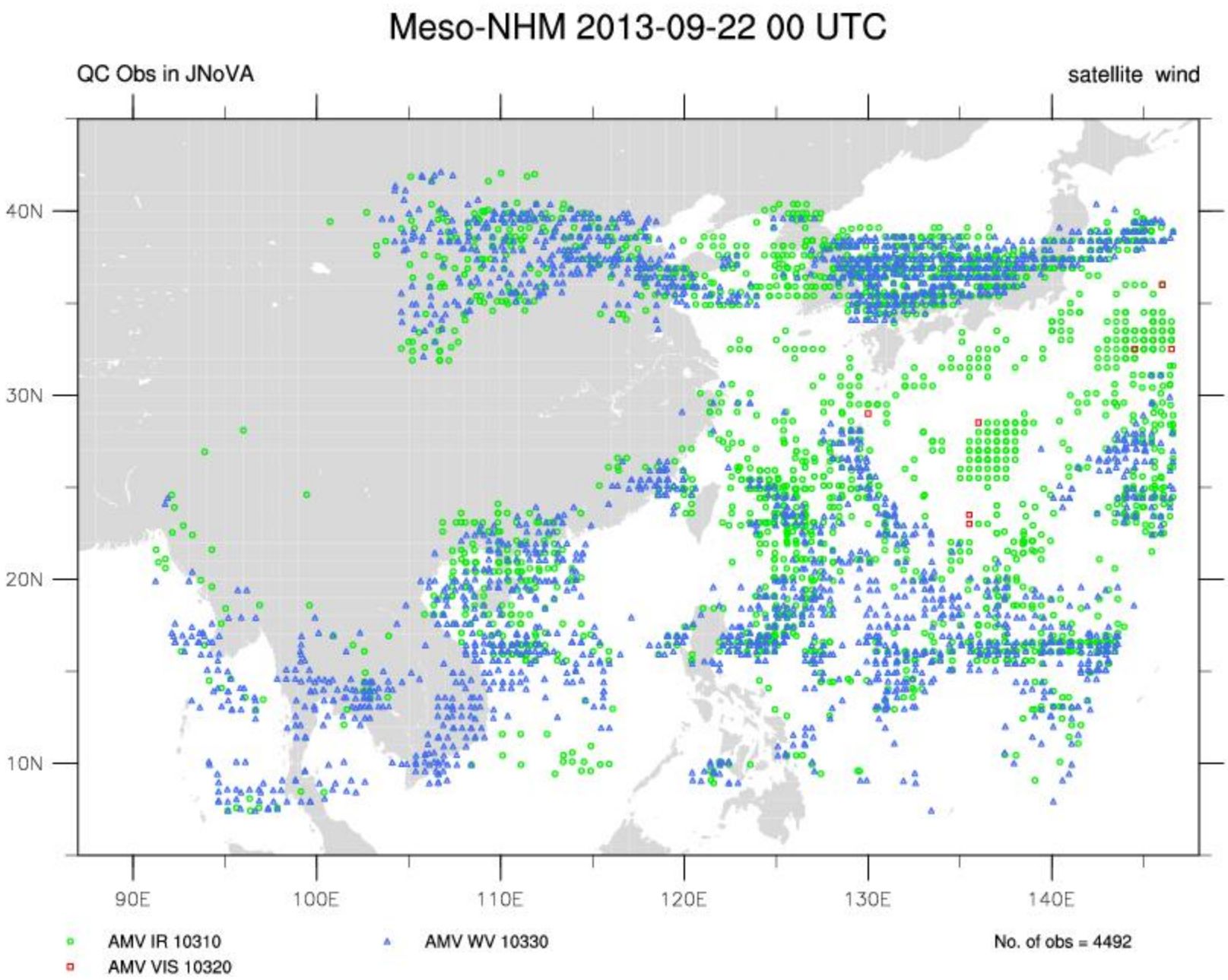
Operational HPC Platform at HKO

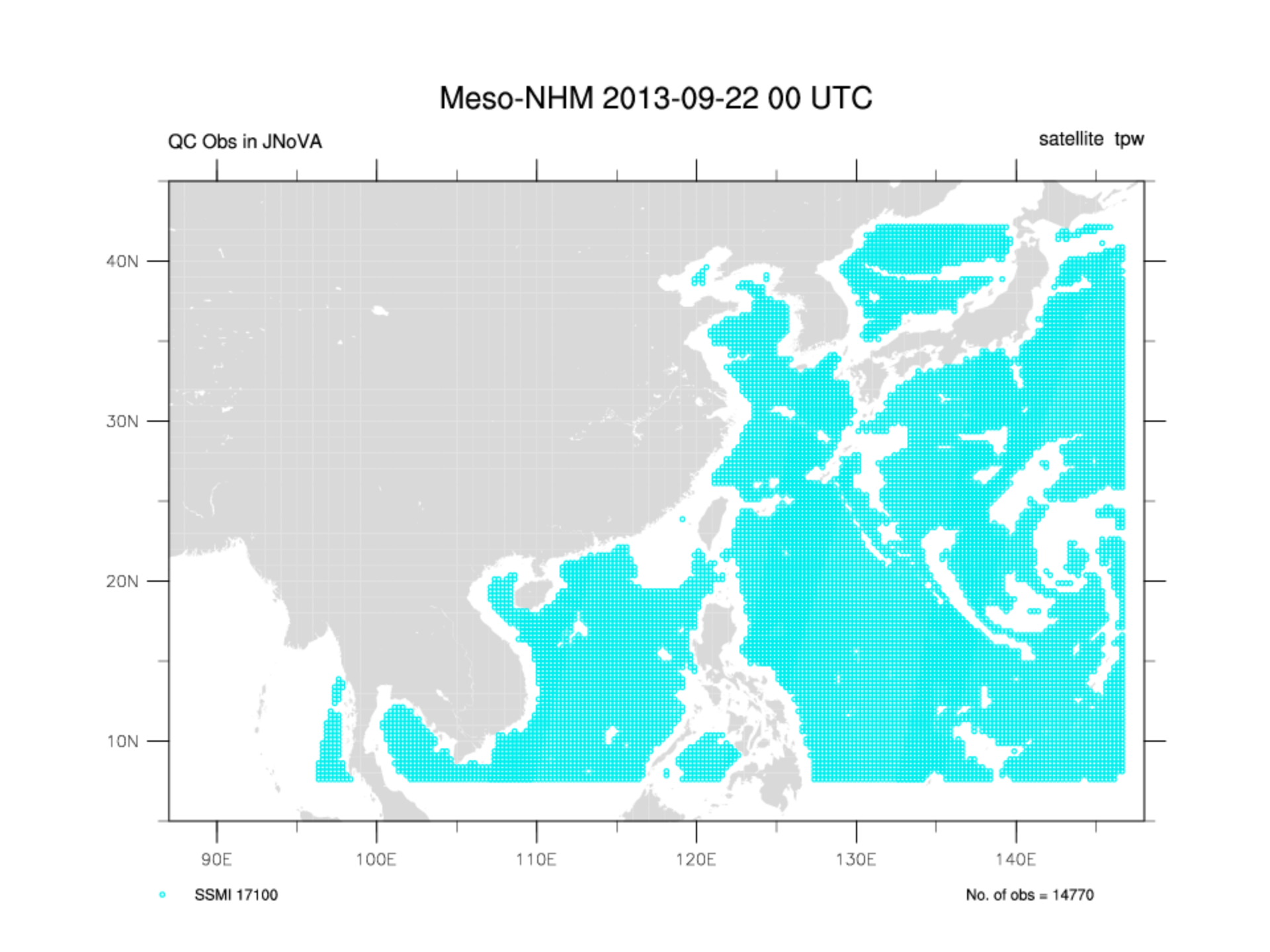
- NWP Integrated Computing Environment (NICE)
- Linux clusters with total peak performance at 7.7 TFLOPS
  - Operation and R&D clusters
  - AIR/NHM Forecast Model System
  - Pre-processing
  - Post-processing and product generation
  - Environment for R&D on NWP and its application development


Meso-NHM 2013-09-22 00 UTC
QC Obs in JNoVA
surface temp
40N
30N
20N
10N
90E
100E
110E
120E
130E
140E
SYNOP 1100
AWS 1200
SHIP 2200
No. of obs = 1307

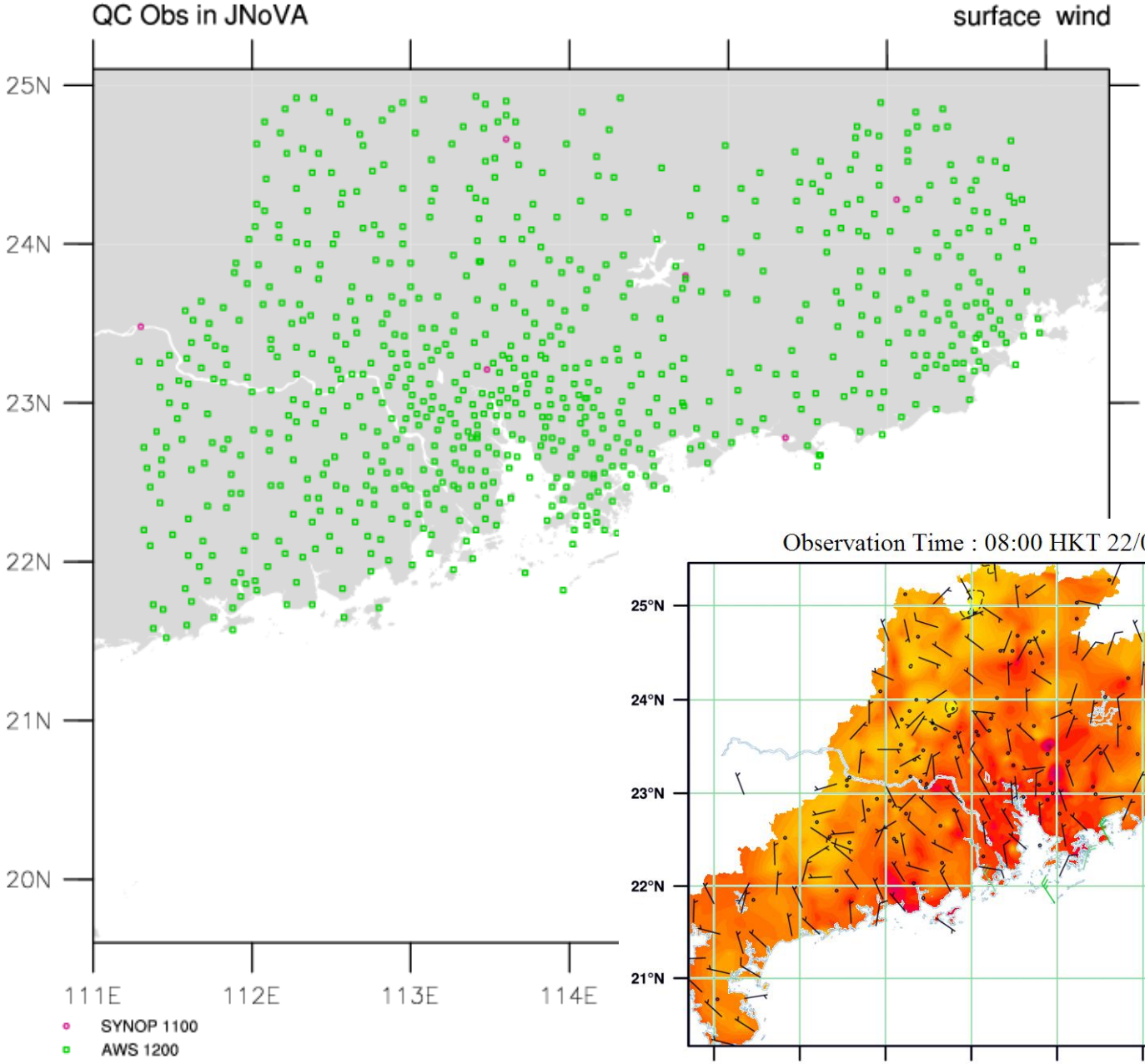

Meso-NHM 2013-09-22 00 UTC
QC Obs in JNoVA
surface wind
40N
30N
20N
10N
90E
100E
110E
120E
130E
140E
SYNOP 1100
AWS 1200
SHIP 2200
No. of obs = 1299


Meso-NHM 2013-09-22 00 UTC
QC Obs in JNoVA
upper temp
40N
30N
20N
10N
90E
100E
110E
120E
130E
140E
TEMP 3000
TEMP-PILOT 3010
AMDAR 4200
AMDAR BUFR 4210
No. of obs = 4496

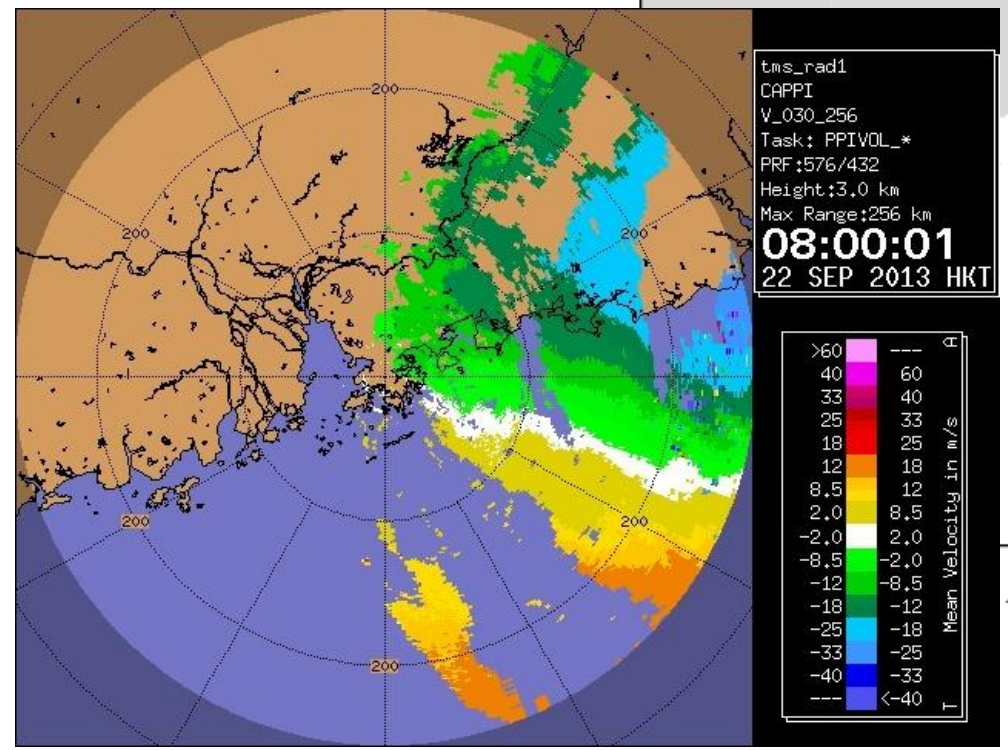

Meso-NHM 2013-09-22 00 UTC
QC Obs in JNoVA
satellite wind
40N
30N
20N
10N
90E
100E
110E
120E
130E
140E
AMV IR 10310
AMV VIS 10320
AMV WV 10330
No. of obs = 4492

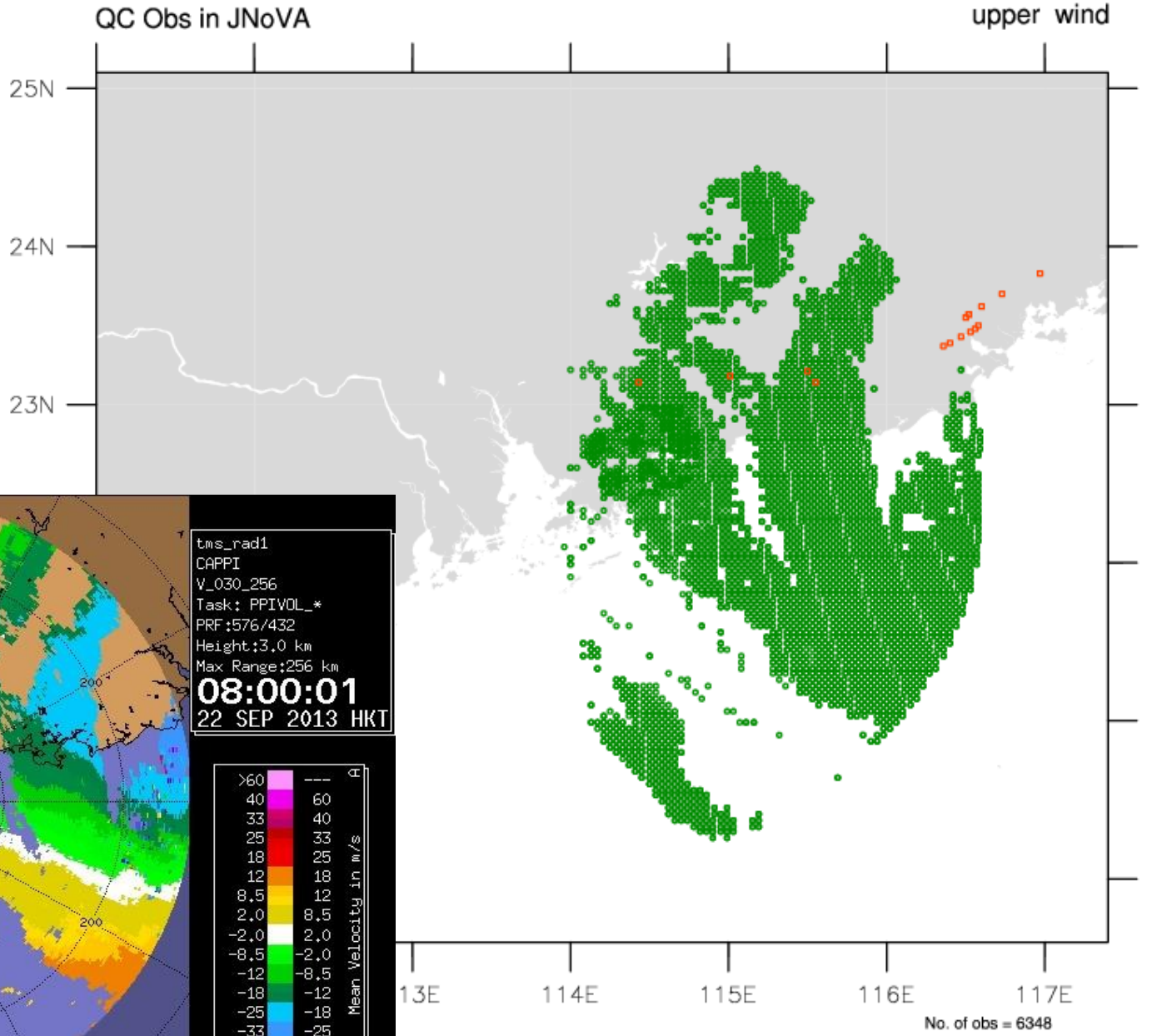

Meso-NHM 2013-09-22 00 UTC
QC Obs in JNoVA
satellite tpw
40N
30N
20N
10N
90E
100E
110E
120E
130E
140E
SSMI 17100
No. of obs = 14770

RAPIDS-NHM 2013-09-22 00 UTC

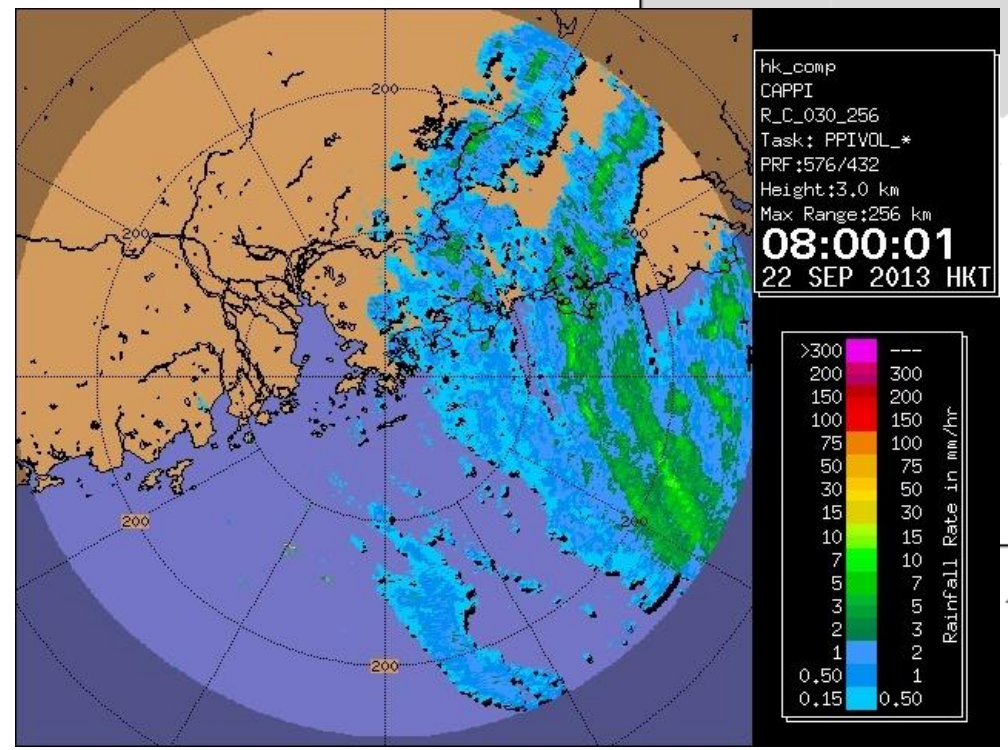


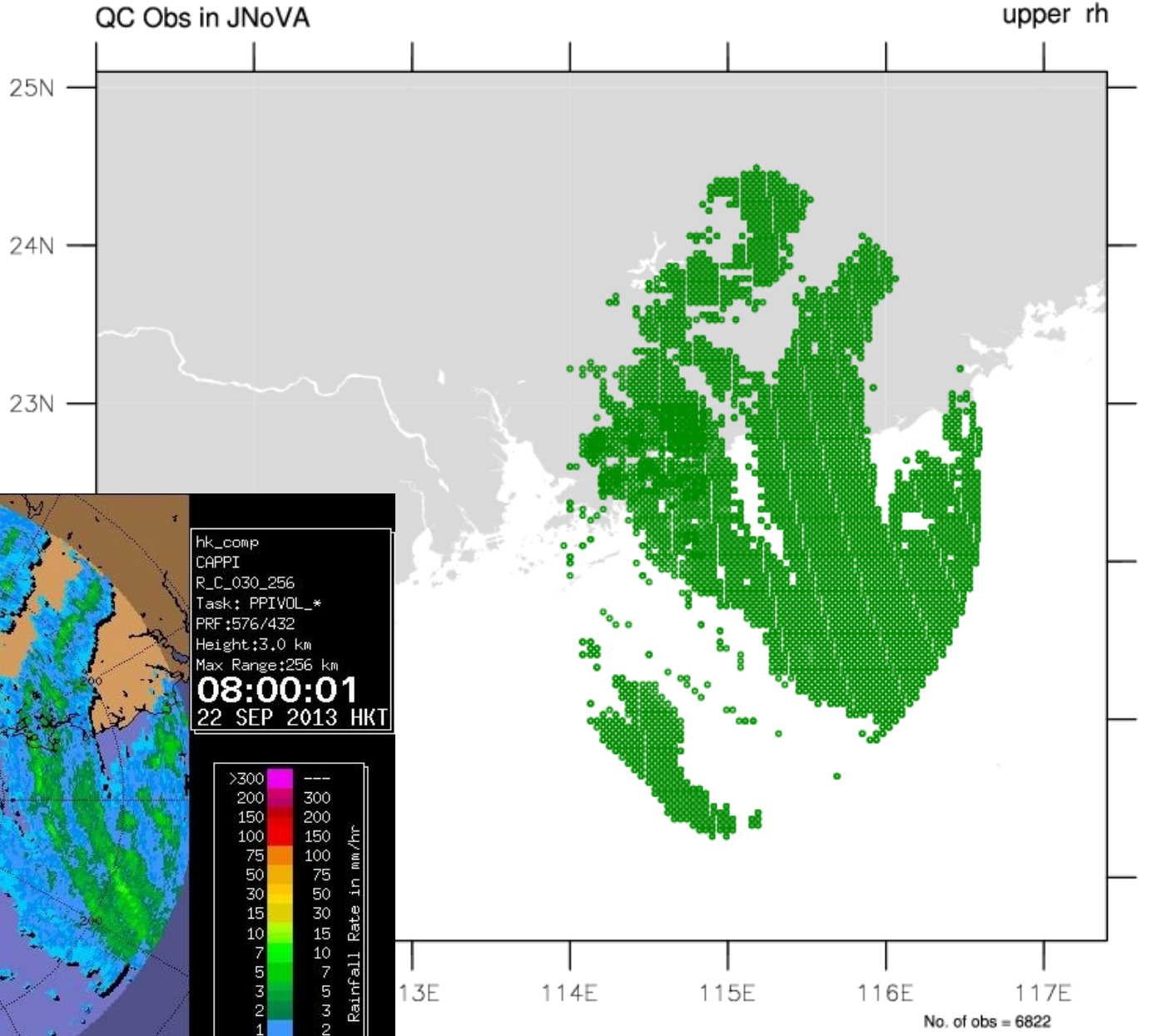
RAPIDS-NHM 2013-09-22 00 UTC





RAPIDS-NHM 2013-09-22 00 UTC



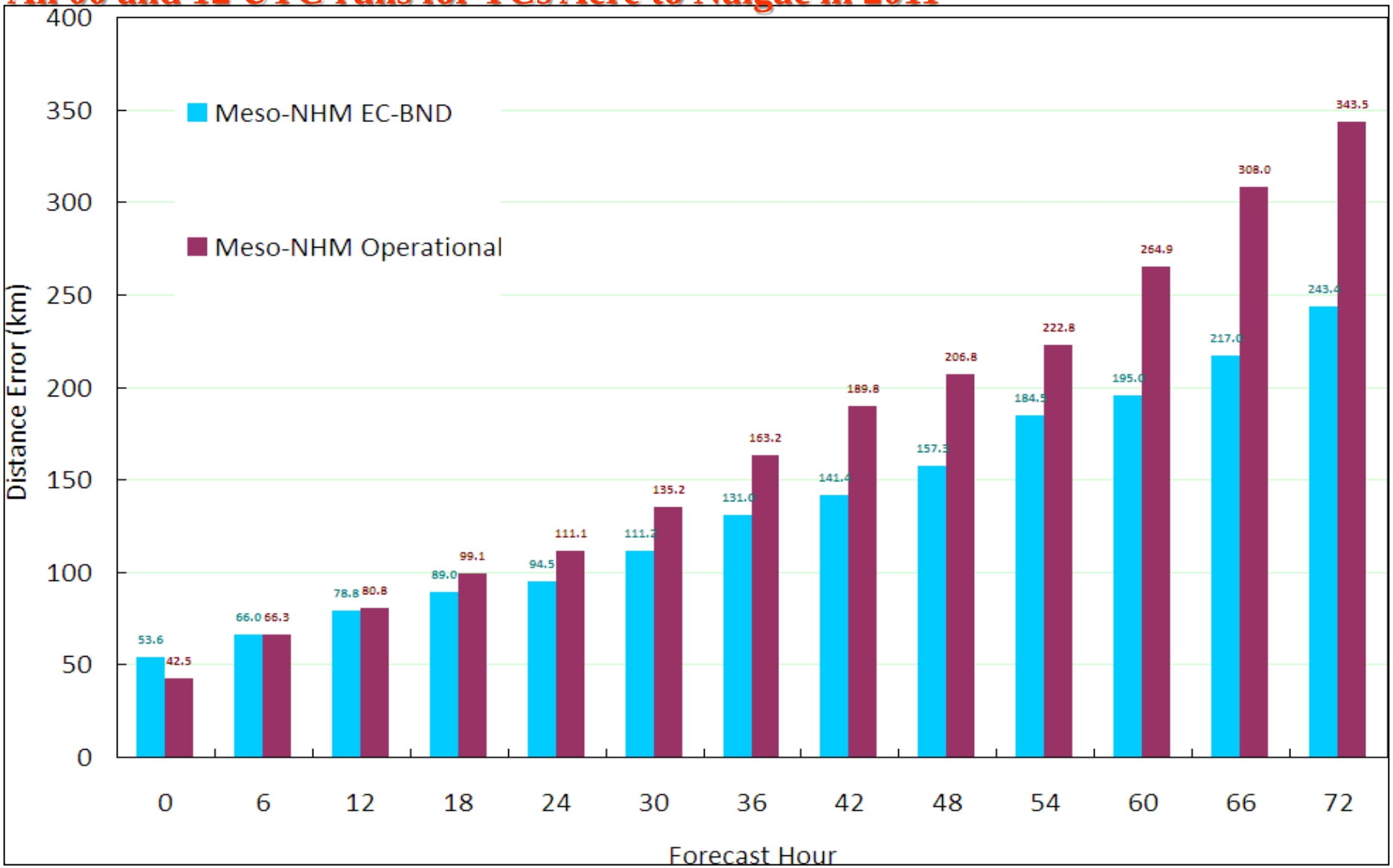


ECMWF as Meso-NHM Boundary Conditions

- Since commencement of operation, JMA-GSM forecast/analysis used as boundary conditions for Meso-NHM
- Sensitivity studies conducted regarding B.C.
  - TC Season of 2011 and 2012 ~ 30 TCs
  - General improvements observed in F/C track errors
- Meso-NHM (ECMWF-boundary) version in operation since 2 April 2013
  - JMA-GSM version run twice daily (00 / 12 UTC) and provides "alternative scenarios"

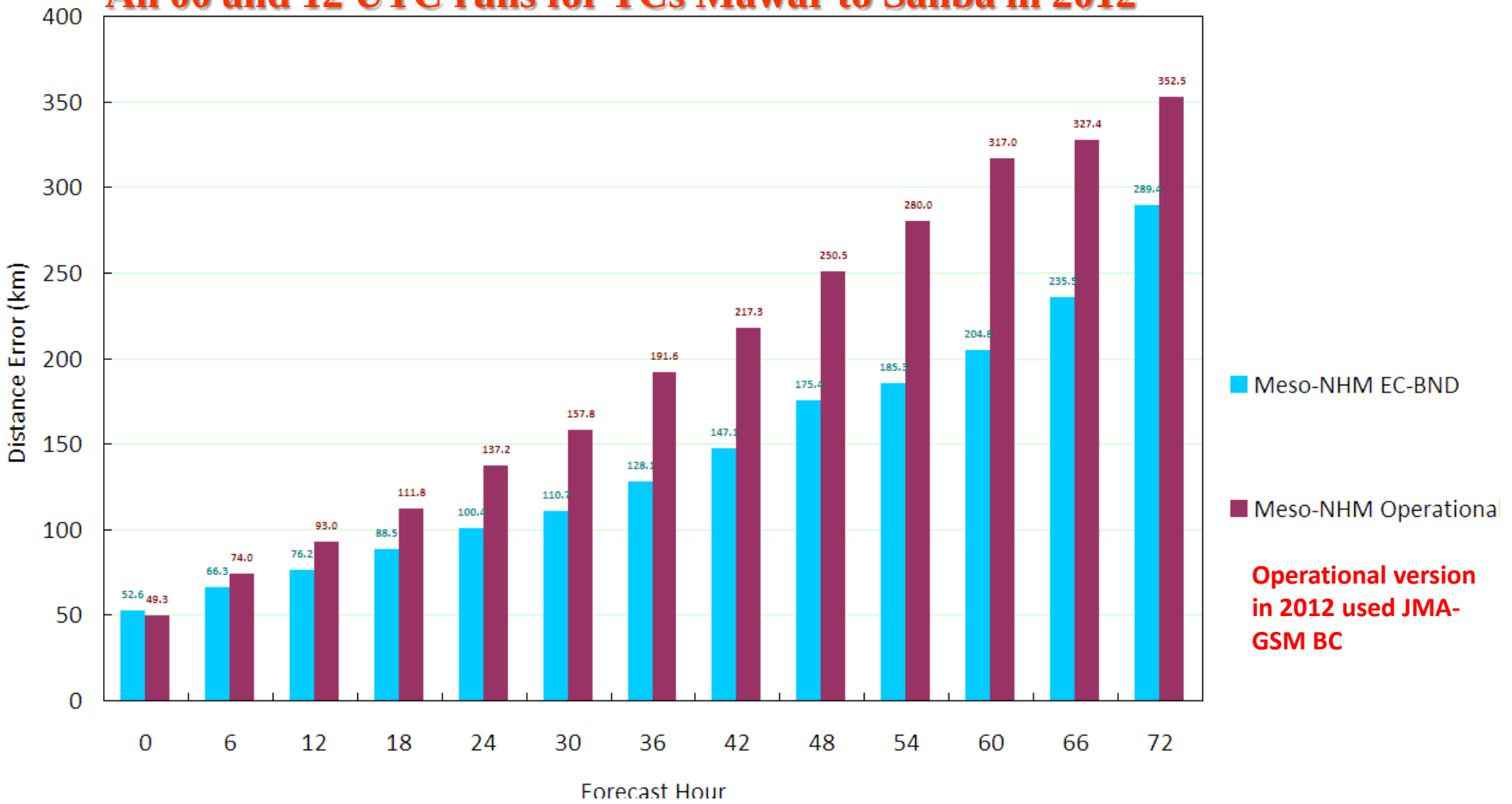
Comparison of Forecast Track Errors

All 00 and 12 UTC runs for TCs Aere to Nalgae in 2011



Comparison of Forecast Track Errors

All 00 and 12 UTC runs for TCs Mawar to Sanba in 2012



Operational version in 2012 used JMA-GSM BC

Assimilation of Radar Reflectivity Data

- Retrieval of RH profiles from radar reflectivity using Bayesian Inversion

maximum likelihood estimate of RH state vector

<=>

1DVAR minimization estimate

$$\mathbf{E}(\mathbf{x}) = \int xP(x = x_{true}|y = y_o)dx \quad (1)$$

$$= \sum_i x_i \frac{W_i}{\sum_j W_j} \quad (2)$$

$$W_i \equiv \exp\{-\frac{1}{2}[\mathbf{y_o} - \mathbf{h(x_i)}]^{\mathbf{T}}\mathbf{R}^{-\mathbf{1}}[\mathbf{y_o} - \mathbf{h(x_i)}]\} \quad (3)$$

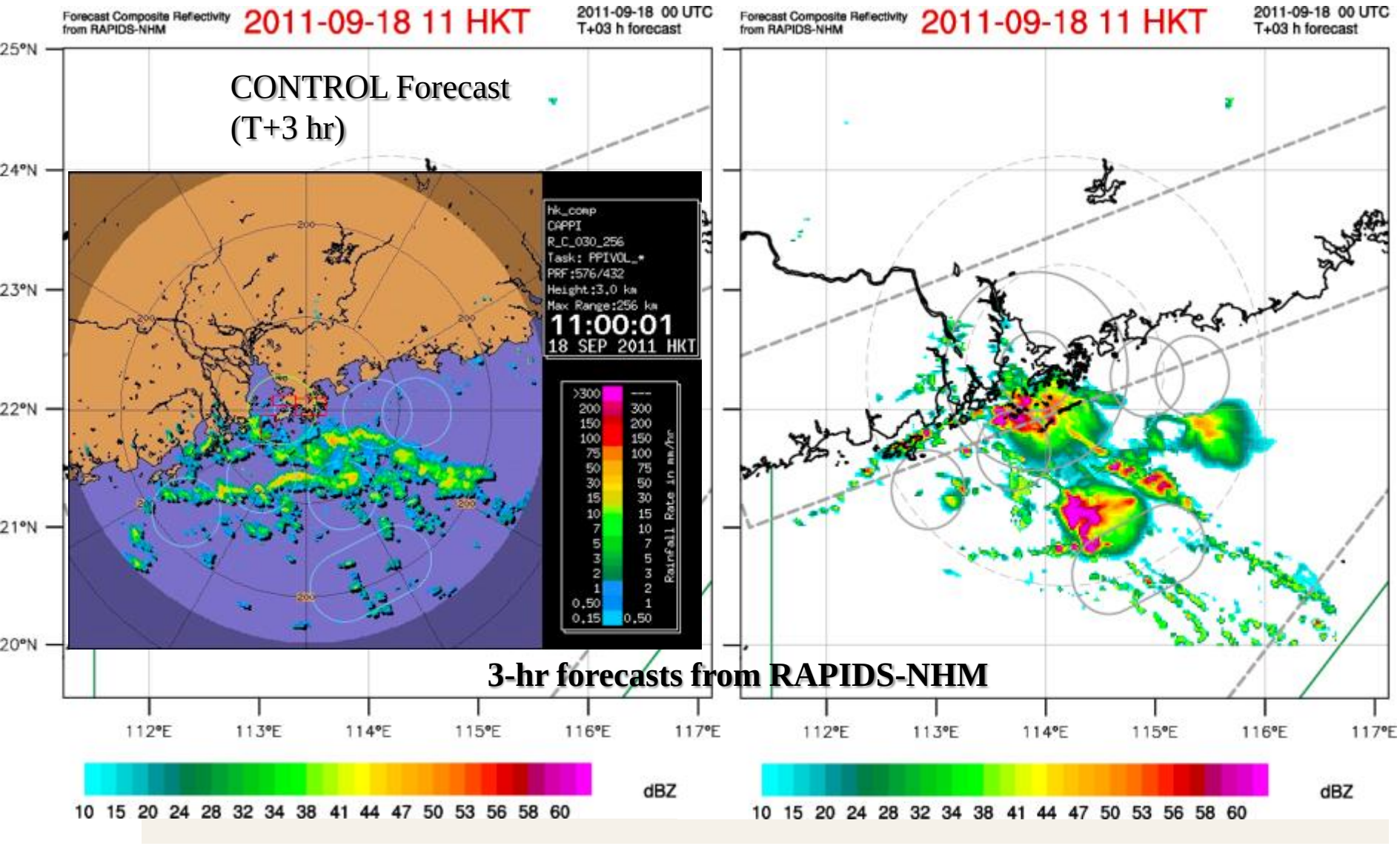
y: observed radar reflectivity

h: forward operator i.e. radar simulator

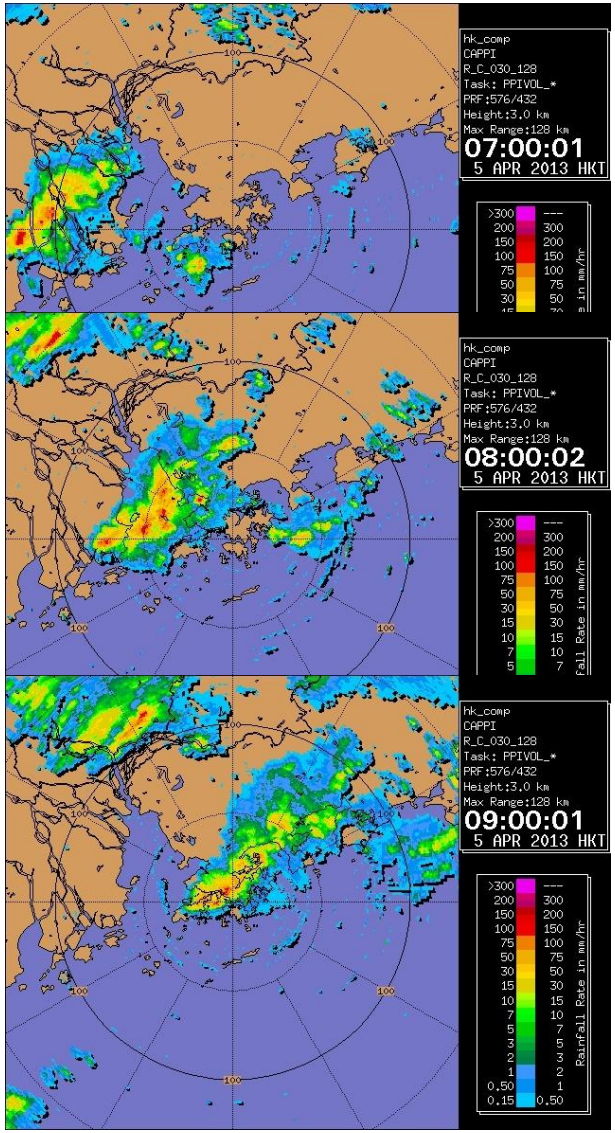
x: model state of cloud variables

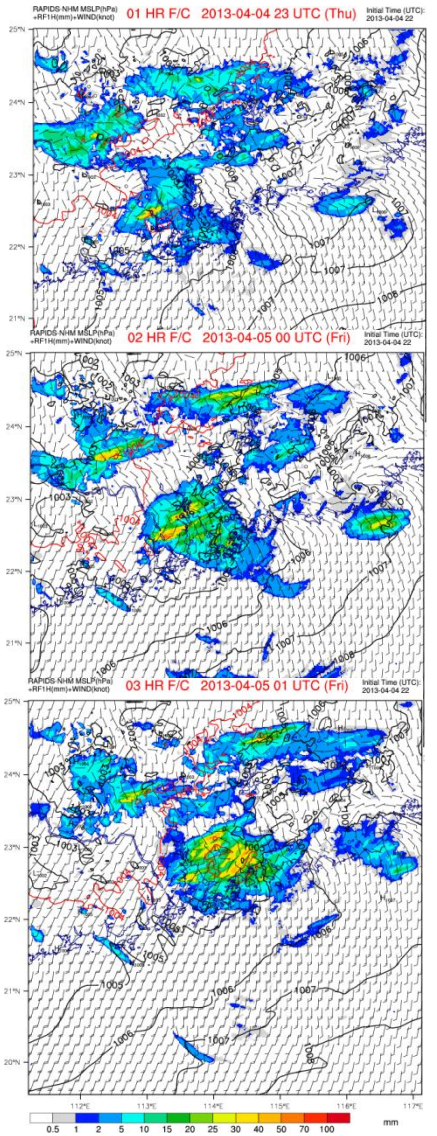
- Retrieved RH profiles assimilated into 3DVAR
  - humidity adjustment
    - » "create" moisture profiles at model "dry" points where non-zero reflectivity exists

Effect of assimilation of radar reflectivity

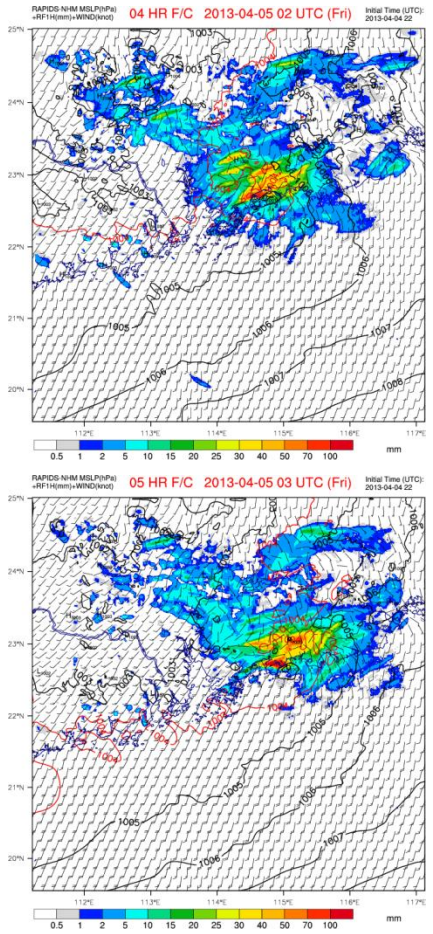


Case of Severe Convection on 2013-04-05

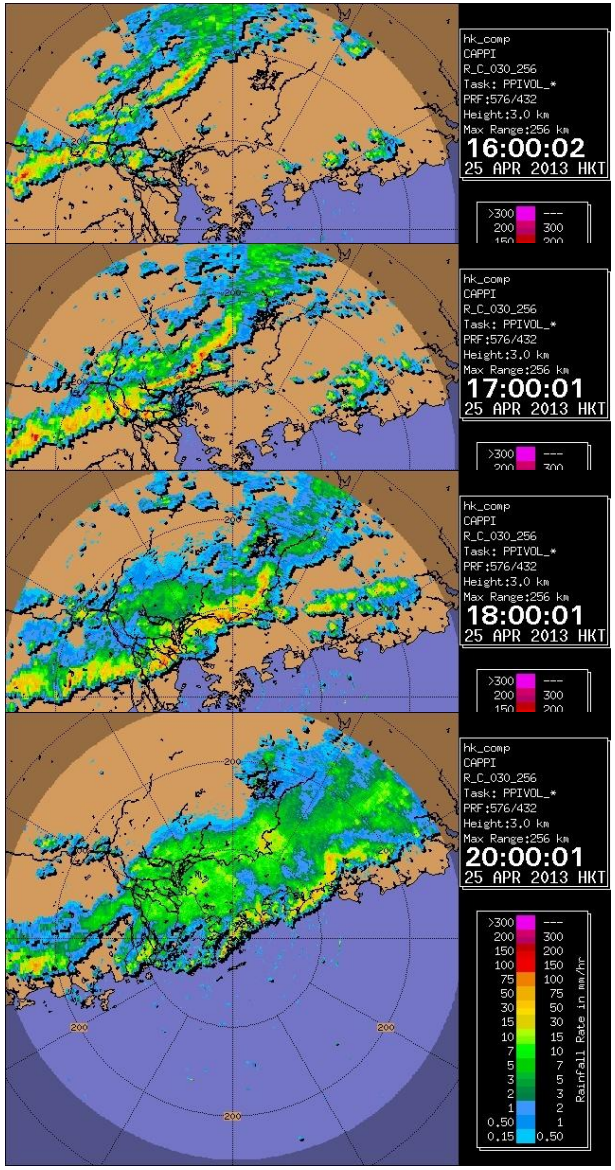


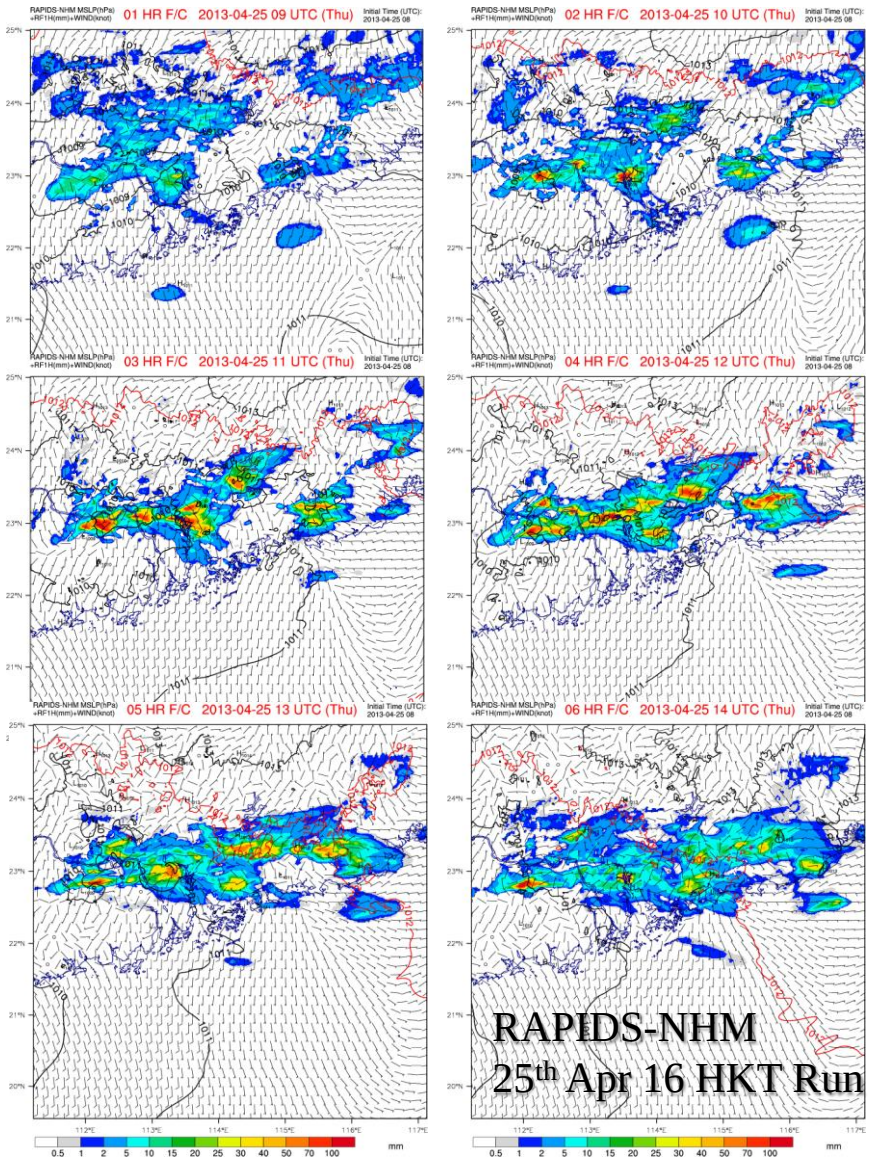


RAPIDS-NHM
5th Apr 06 HKT Run



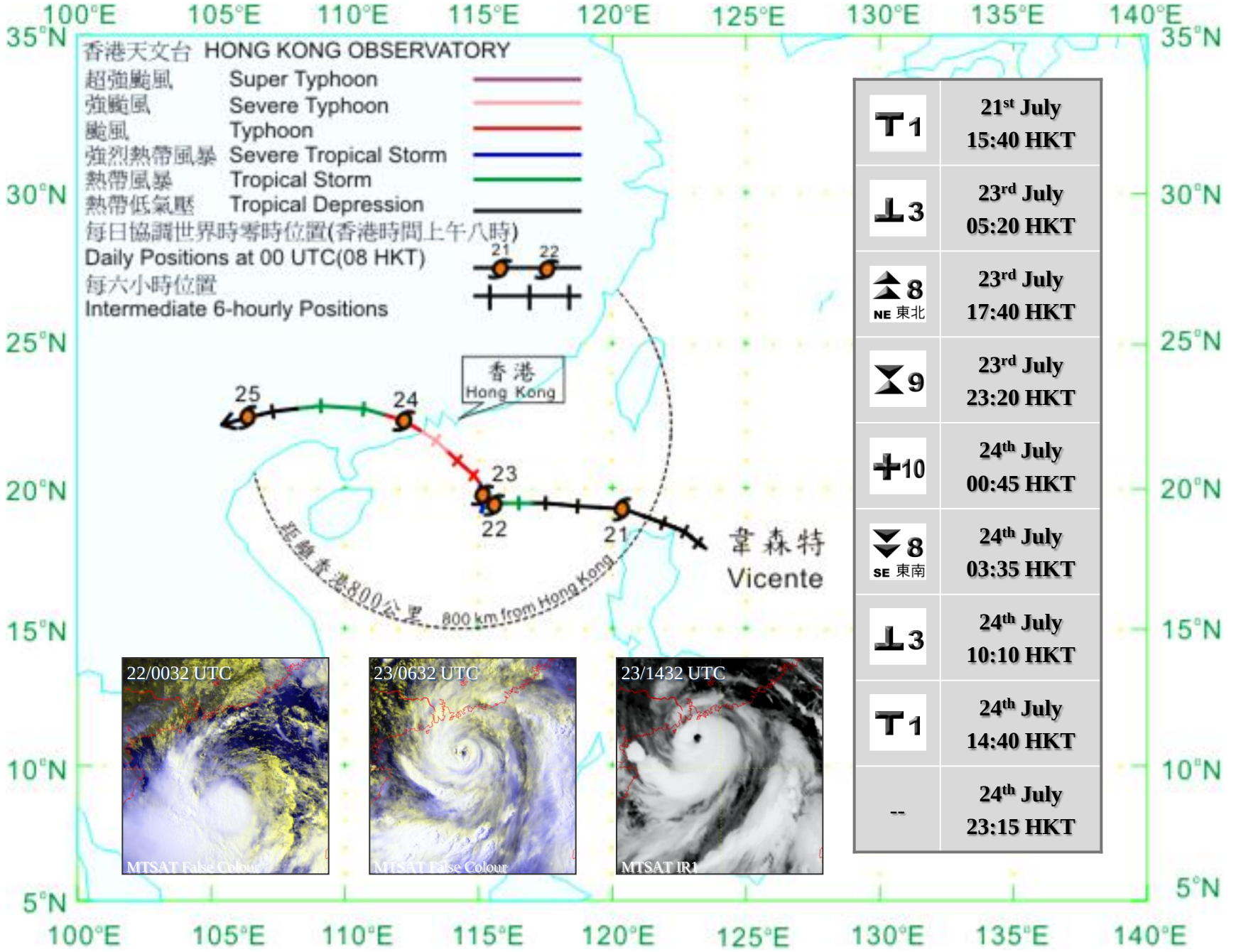
Case of Severe Convection on 2013-04-25



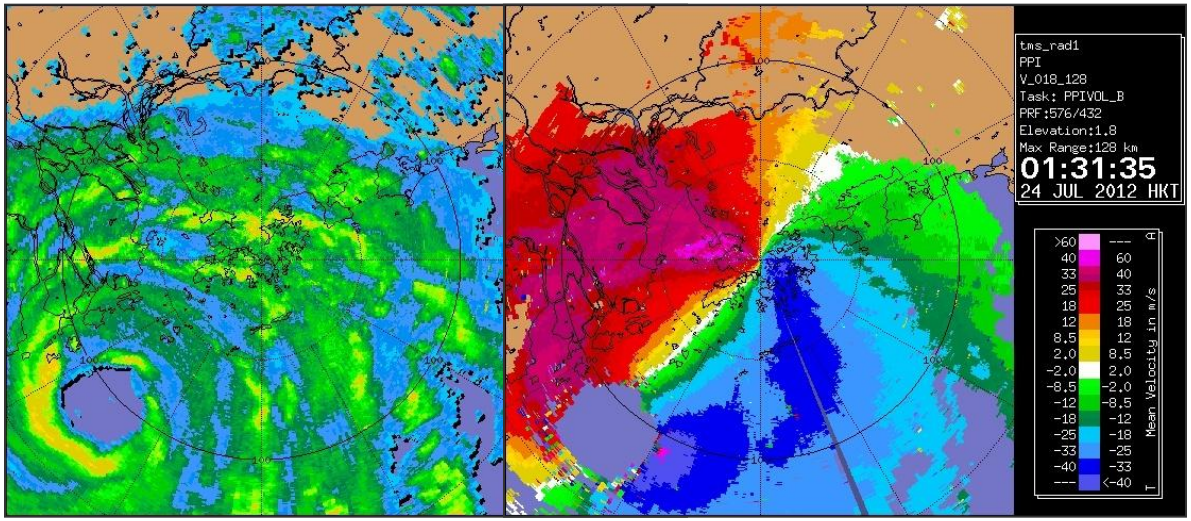


Tropical Cyclone Reconnaissance Flights

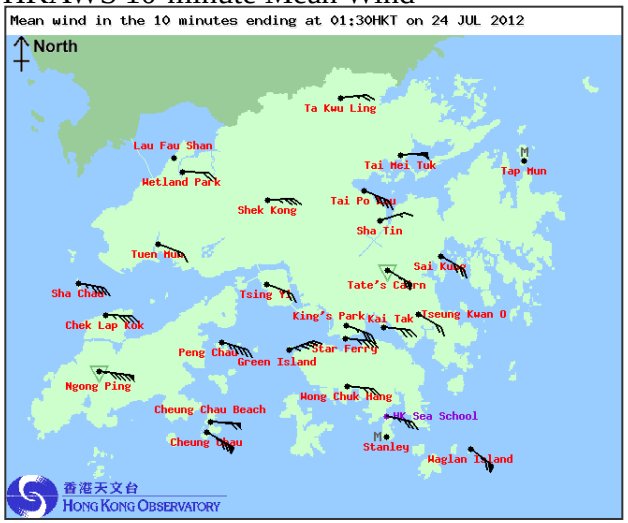
- Collaboration between HKO and the Hong Kong Government Flying Service (GFS)
- More than 10 operations conducted in 2012 – 2013
- Data collection by high-res. probe installed on fixed-wing aircraft of GFS


香港天文台 HONG KONG OBSERVATORY
超強颱風 Super Typhoon
強颱風 Severe Typhoon
颱風 Typhoon
強烈熱帶風暴 Severe Tropical Storm
熱帶風暴 Tropical Storm
熱帶低氣壓 Tropical Depression
每日協調世界時零時位置(香港時間上午八時)
Daily Positions at 00 UTC(08 HKT)
每六小時位置
Intermediate 6-hourly Positions
香港
Hong Kong
韋森特
Vicente
距離香港800公里 800 km from Hong Kong
22/0032 UTC
MTSAT False Colour
23/0632 UTC
MTSAT False Colour
23/1432 UTC
MTSAT IR1
T1 21st July 15:40 HKT
⊥3 23rd July 05:20 HKT
8 NE 東北 23rd July 17:40 HKT
9 23rd July 23:20 HKT
+10 24th July 00:45 HKT
8 SE 東南 24th July 03:35 HKT
⊥3 24th July 10:10 HKT
T1 24th July 14:40 HKT
-- 24th July 23:15 HKT

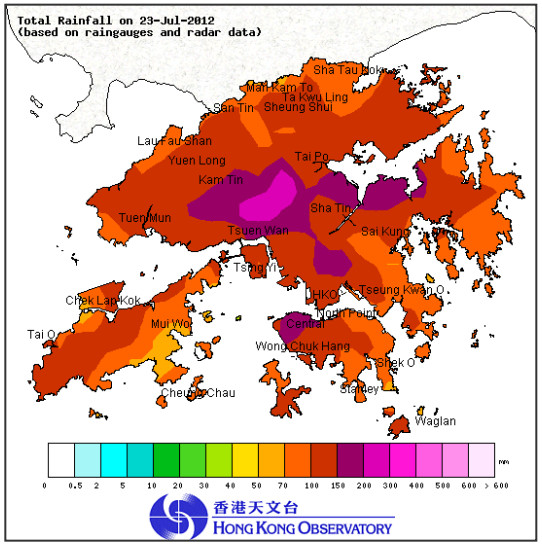
128-km Radar Reflectivity (3-km CAPPI) and Doppler Velocity (1.8-deg Elevation)

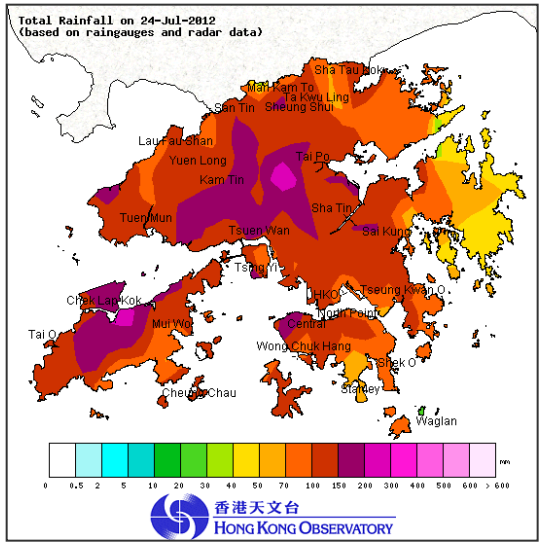


HKAWS 10-minute Mean Wind



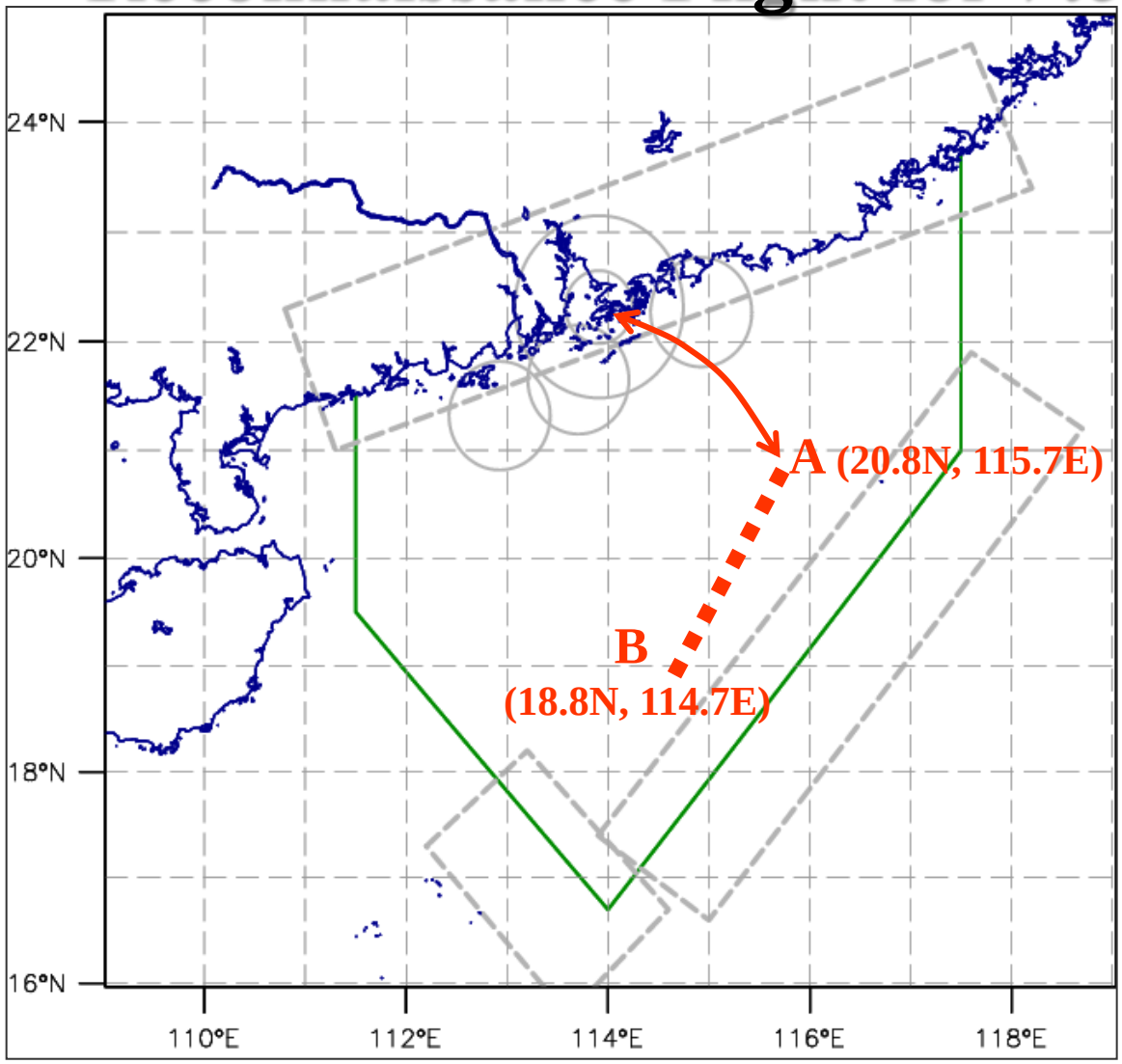
24-hourly Rainfall over Hong Kong on 23rd and 24th July 2012 (HKT)





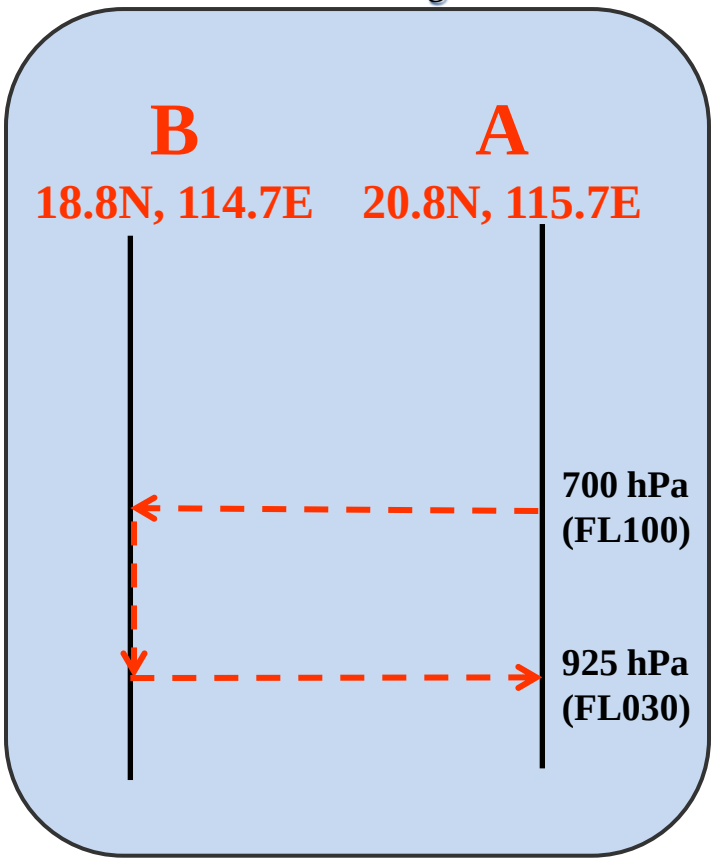
Weather Warnings issued by HKO on 24th July 2012	
Amber 黃	01:55 – 10:40 HKT
雷暴 Thunderstorm	00:15 – 05:15 HKT
	01:55 – 12:25 HKT
	01:10 – 15:00 HKT

Reconnaissance Flight for *Vicente* (2012)

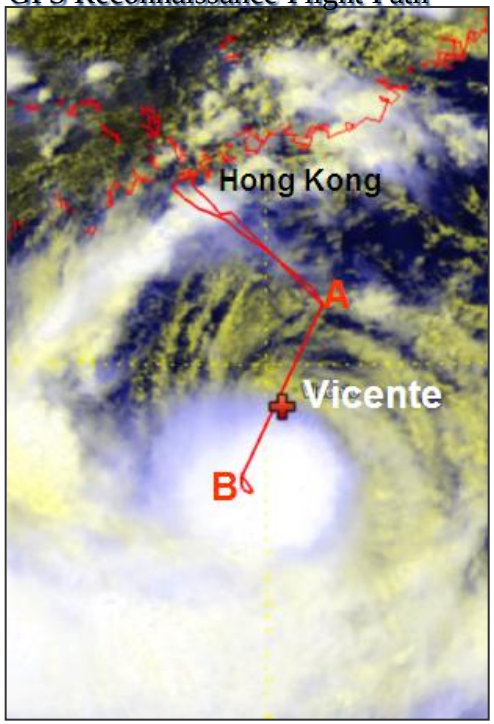


GFS Reconnaissance Flight Path, 06 UTC, 22nd July 2012

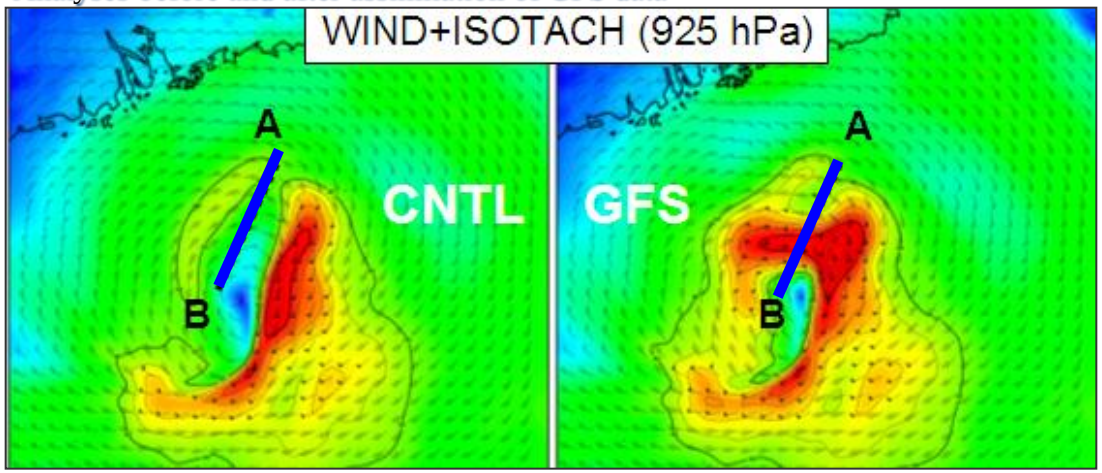
Cross-section of Flight Path



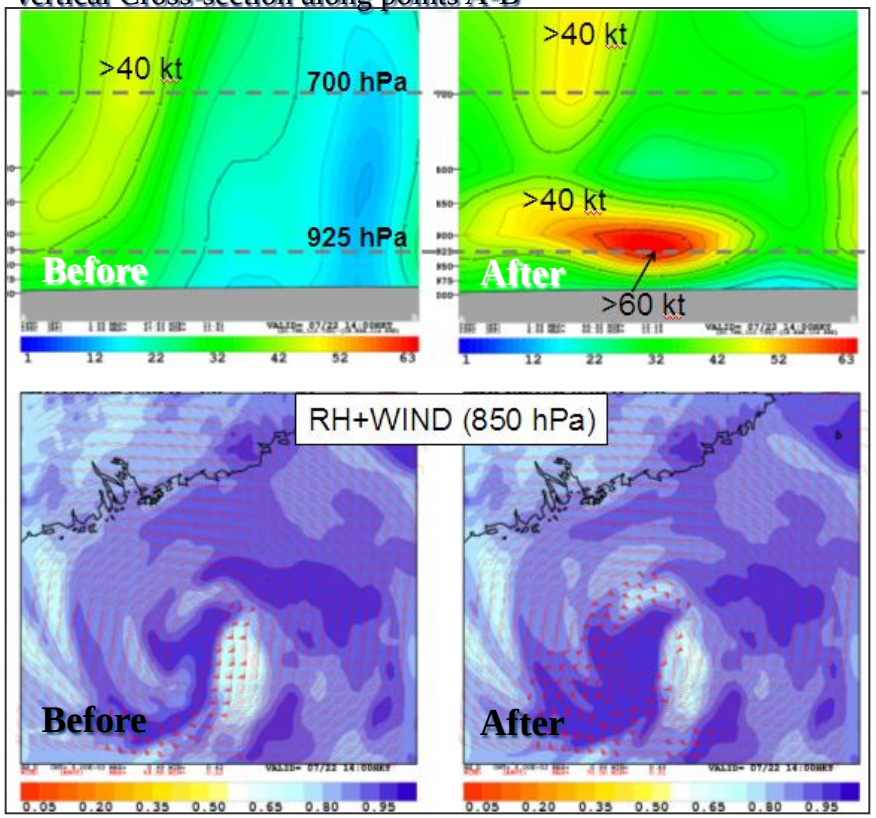
GFS Reconnaissance Flight Path



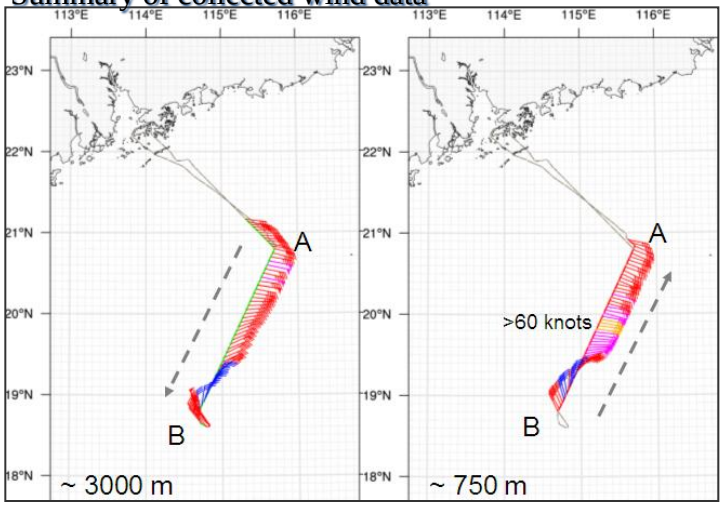
Analyses before and after assimilation of GFS data



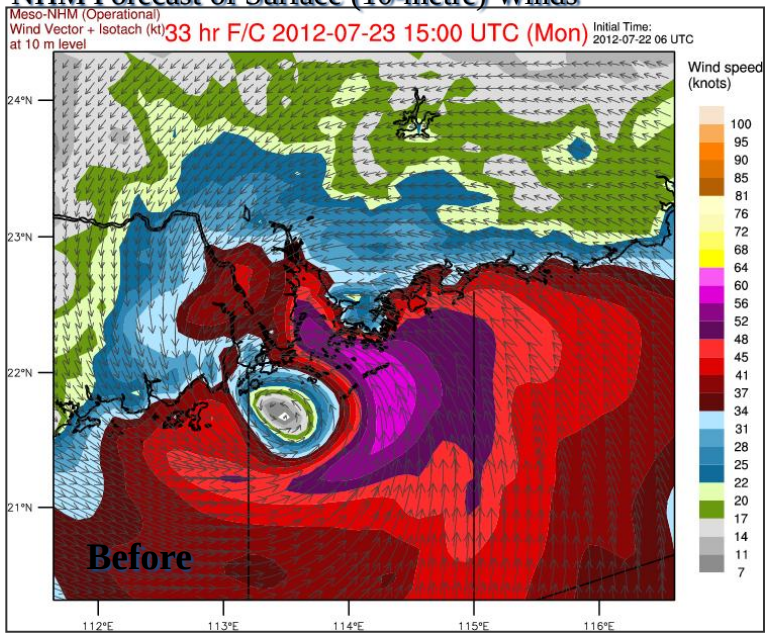
Vertical Cross-section along points A-B

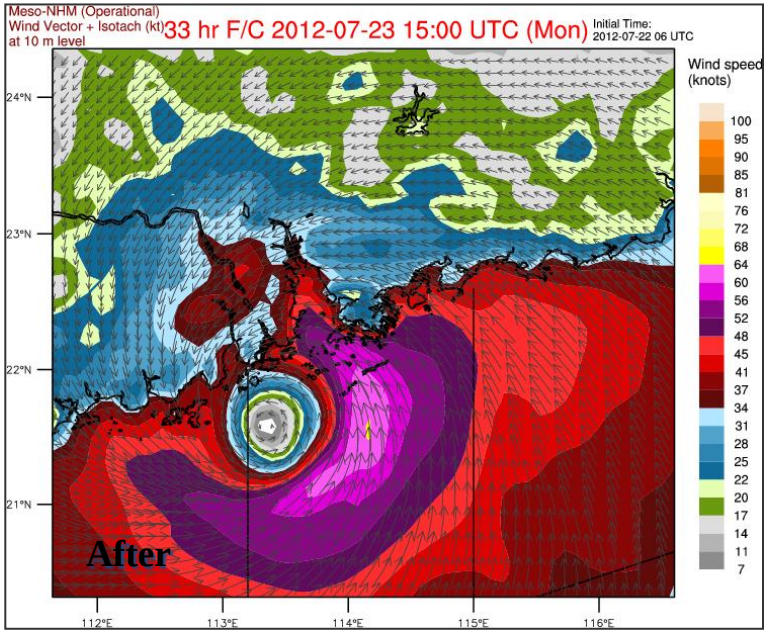


Summary of collected wind data

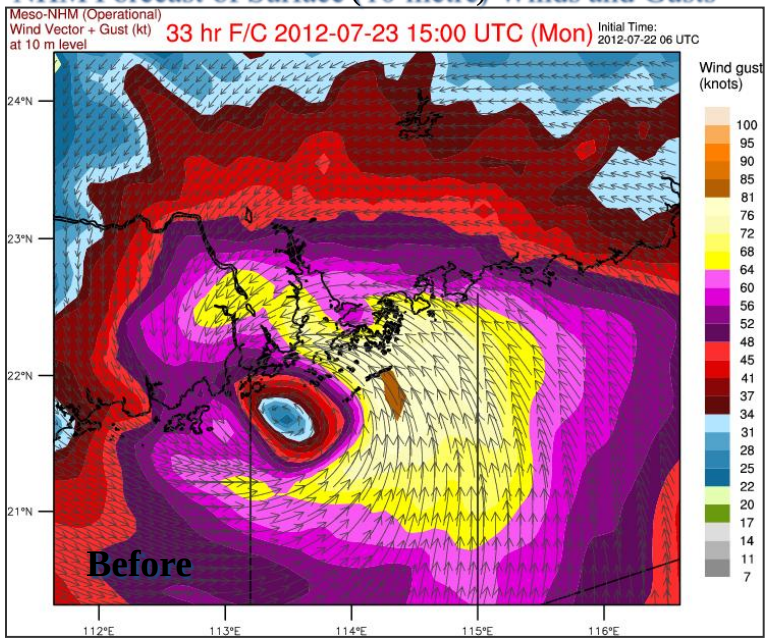


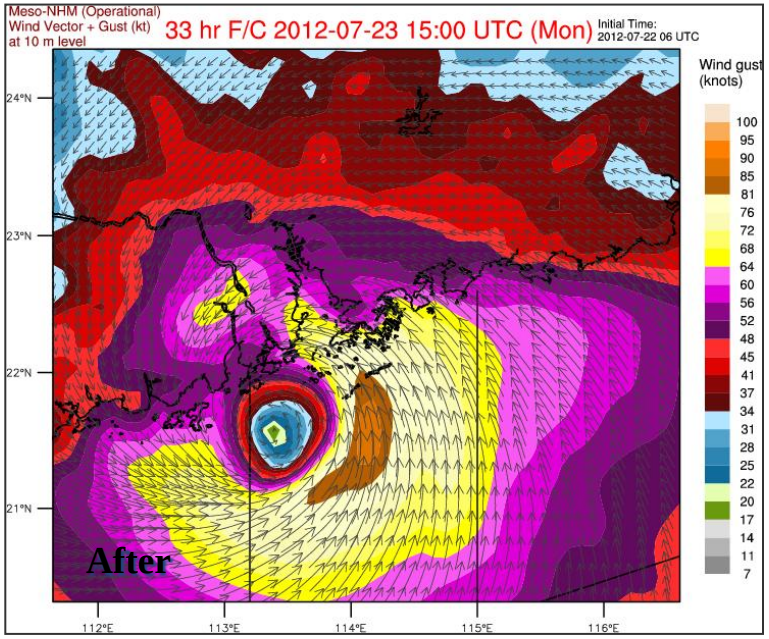
NHM Forecast of Surface (10-metre) Winds





NHM Forecast of Surface (10-metre) Winds and Gusts



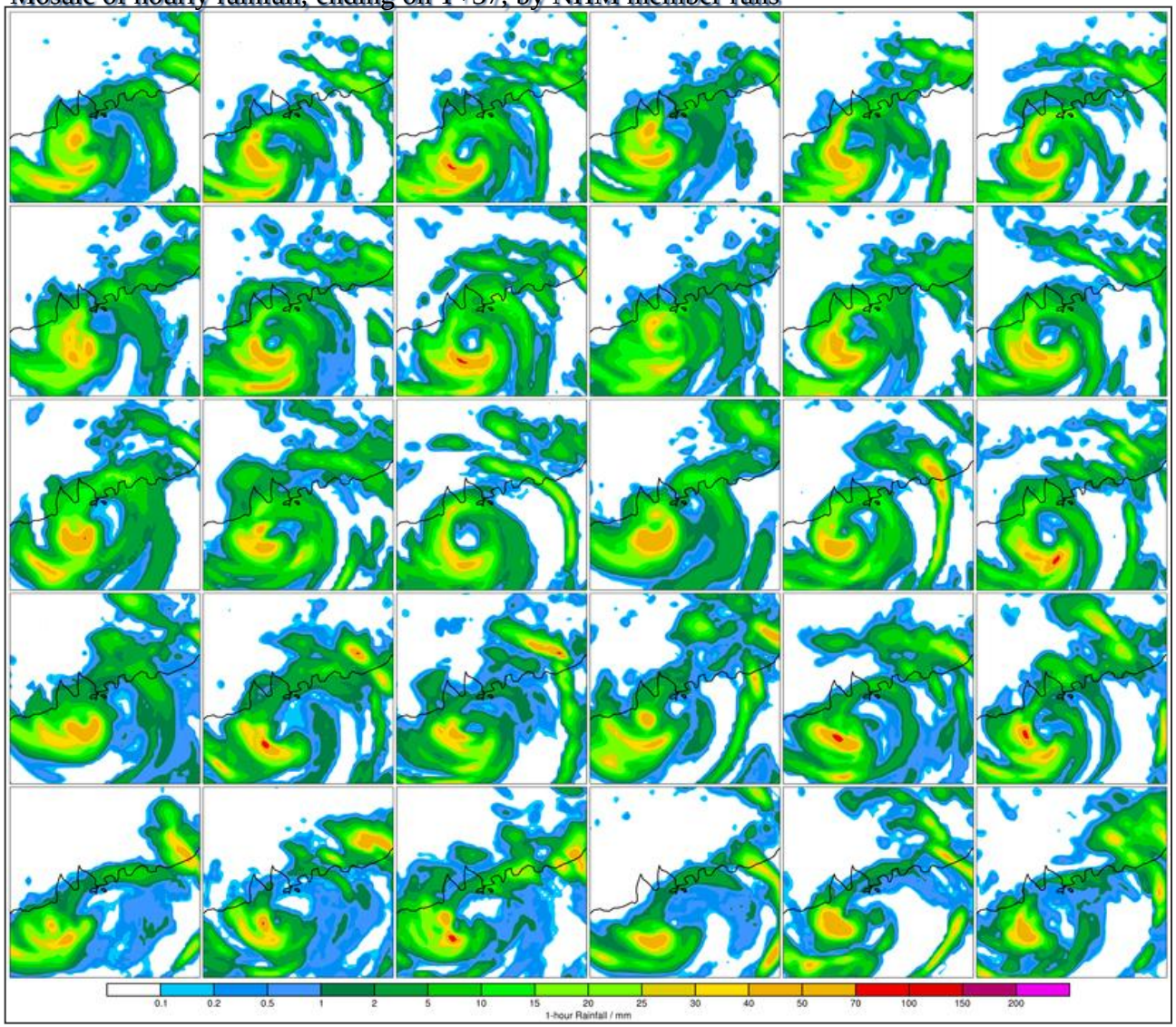


Control Run

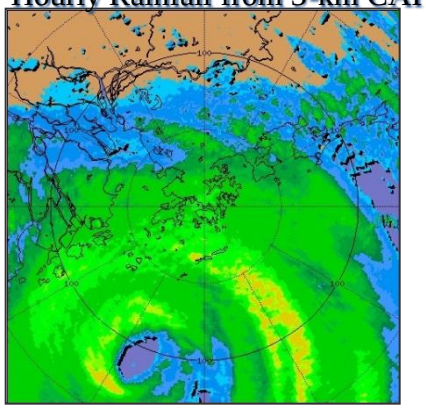
With GFS Data

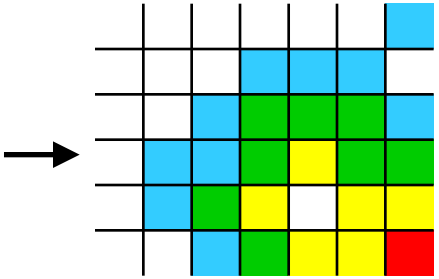
Further Experiments on *Vicente*

Mosaic of hourly rainfall, ending on T+37, by NHM member runs



Hourly Rainfall from 3-km CAPPI





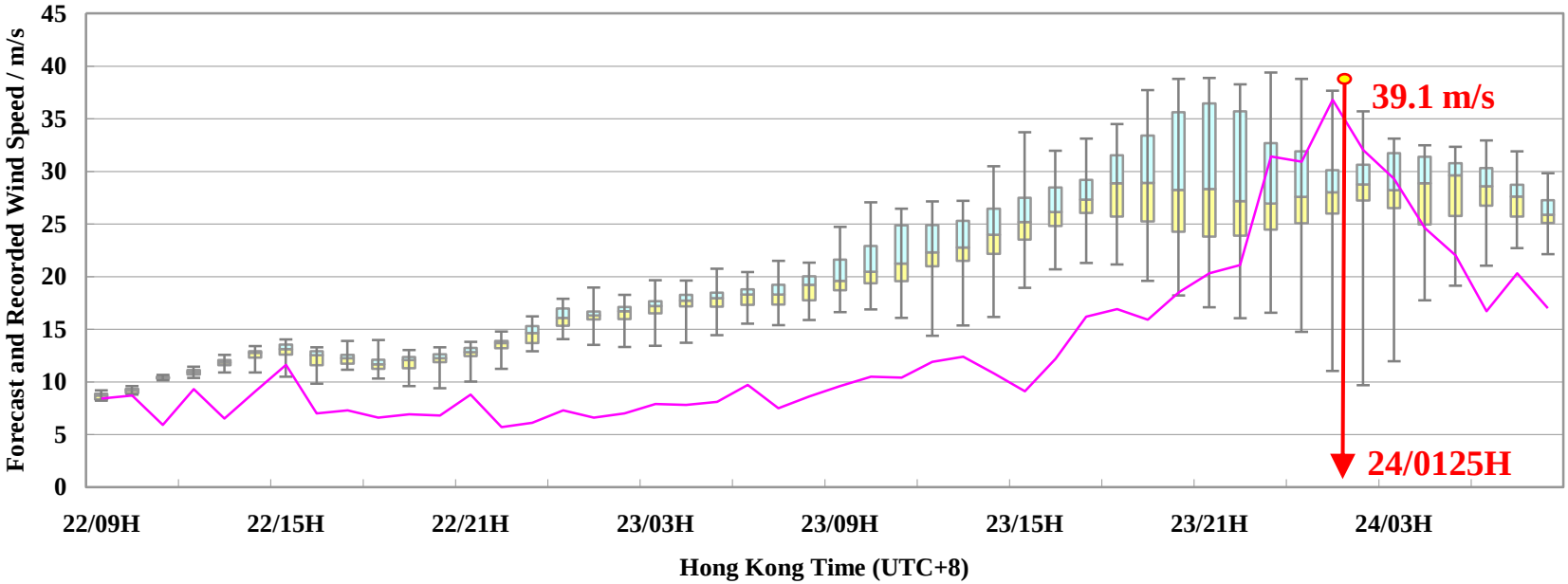
Fractional Coverage

$$= \frac{\text{Grid points exceeding } x \text{ mm/hr}}{\text{Grid points within study area}}$$

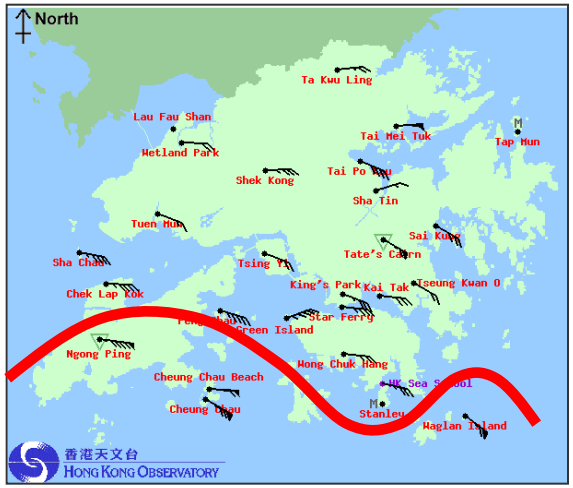
- Within 250 km from Tai Mo Shan Radar
  - 2285 NHM grid-points
  - 180942 radar pixels

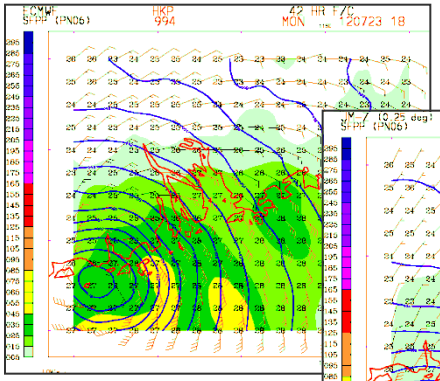
Vicente – Forecasts of Local Winds

10-minute mean wind, plotted every hour, recorded at Cheung Chau AWS (pink) and NHM forecast (box-and-whisker)



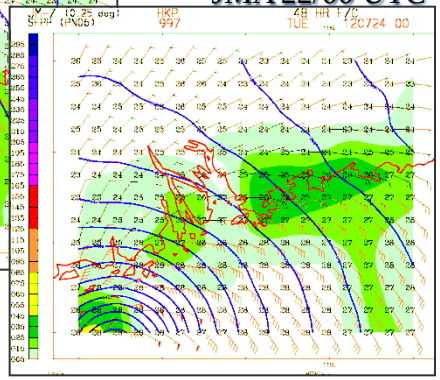
10-min. Mean Winds at 01:30 HKT



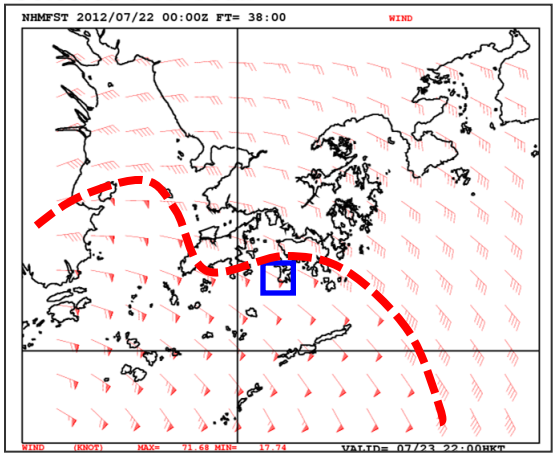


ECMWF 22/00 UTC

JMA 22/00 UTC

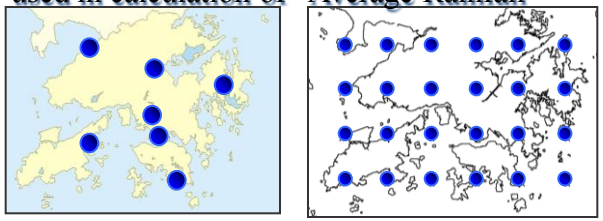


Selected NHM run

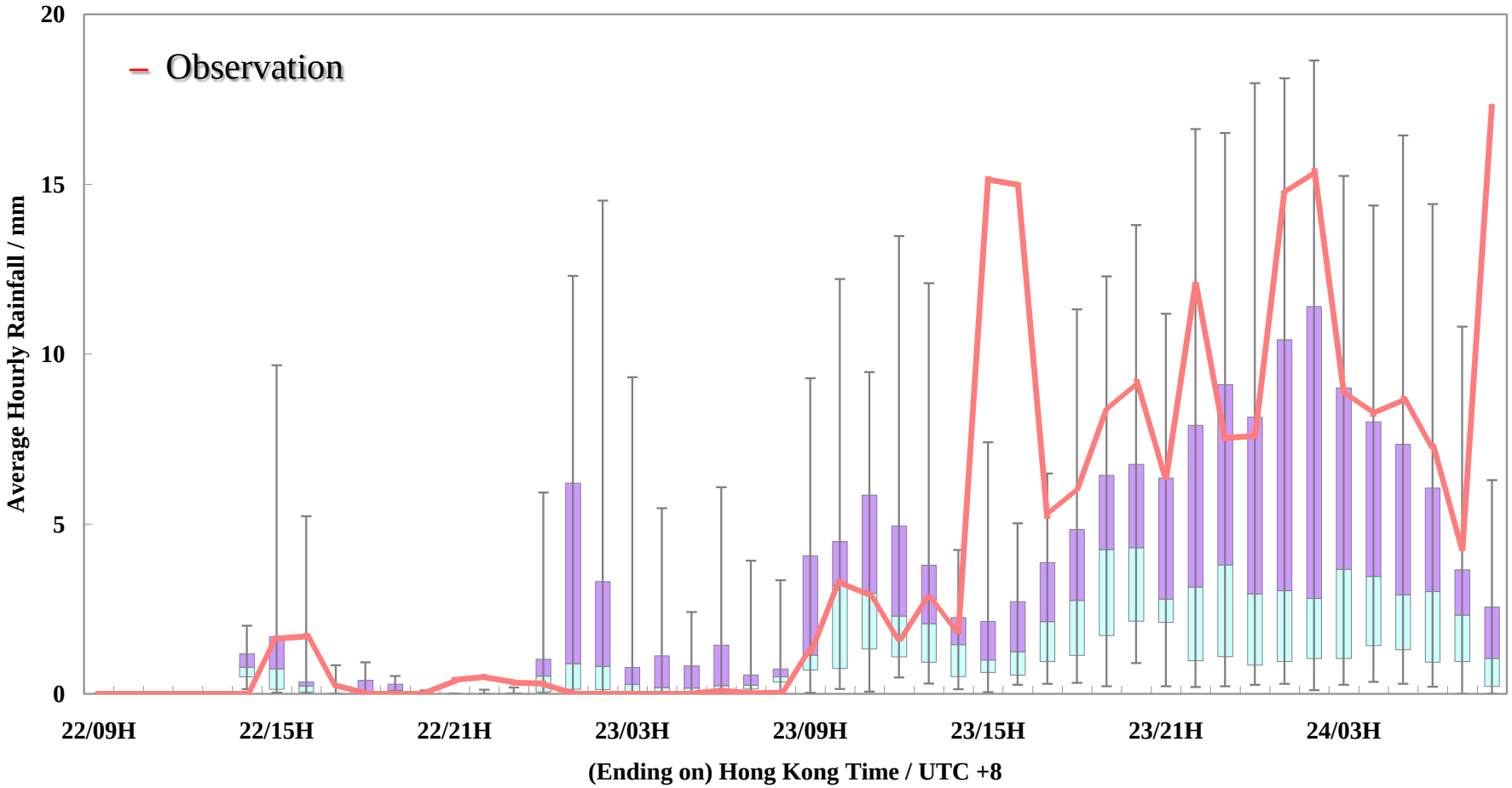


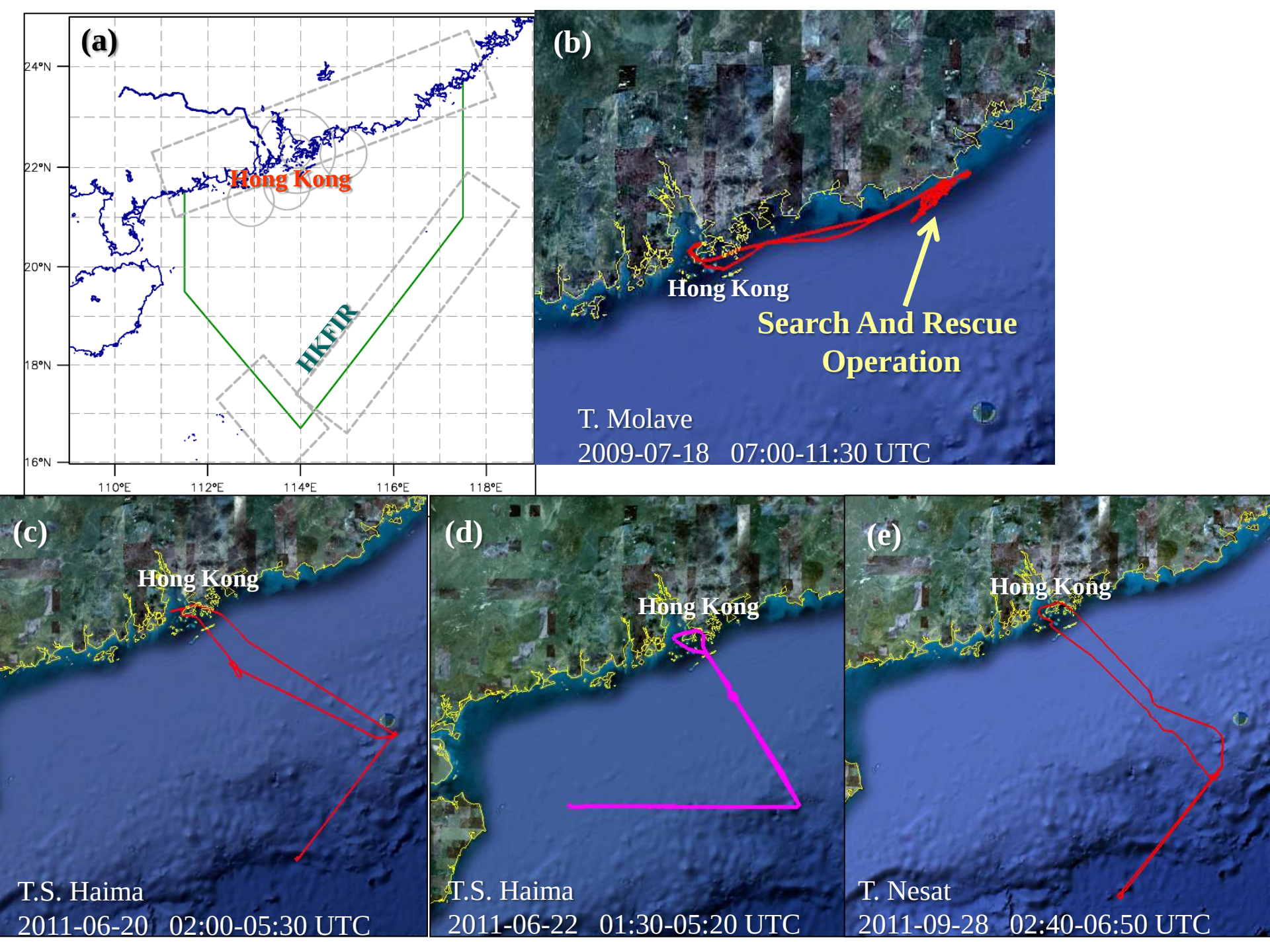
Vicente – Local Rainfall Forecasts

HKAWS Raingauges and NHM grid-points used in calculation of "Average Rainfall"

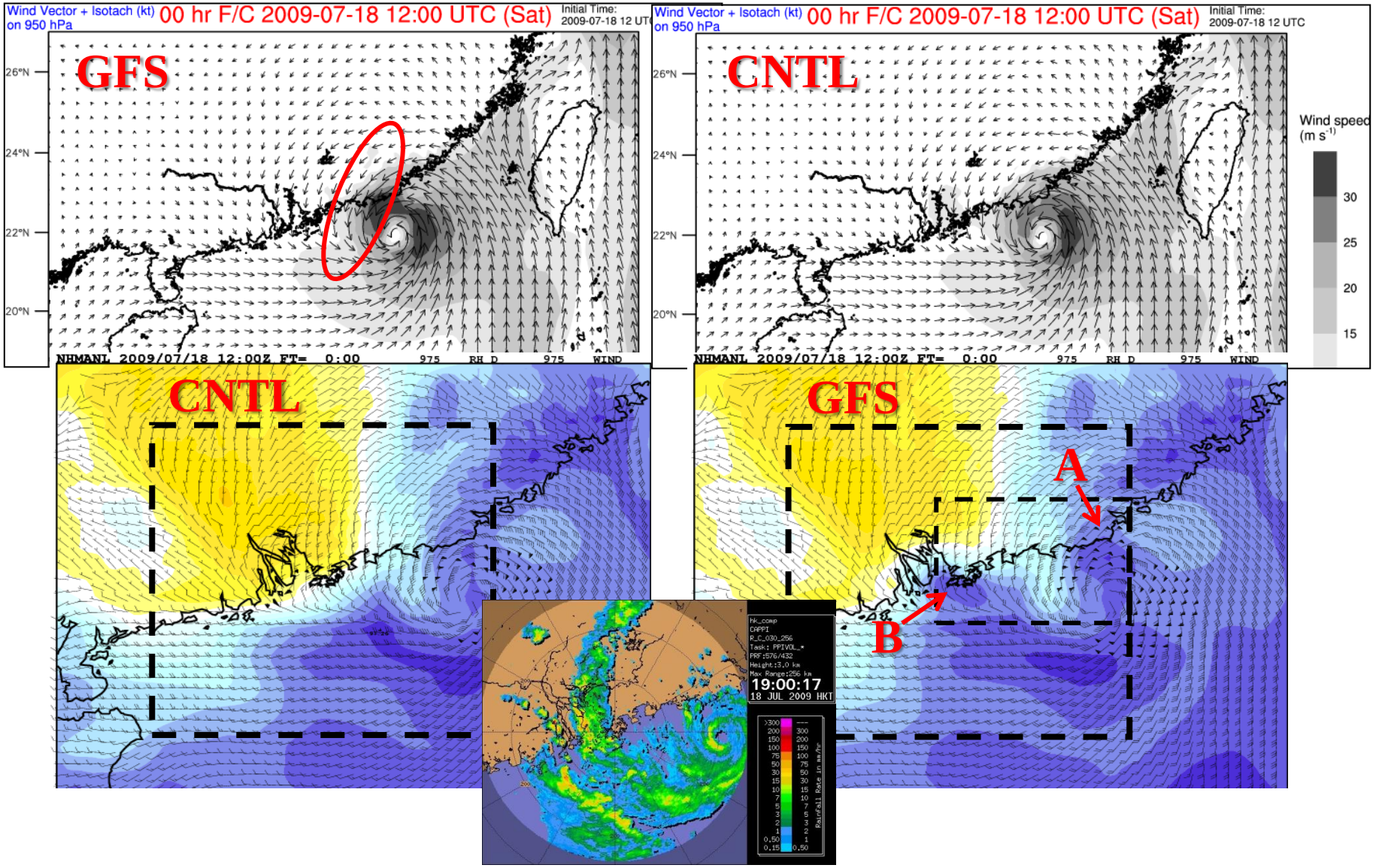


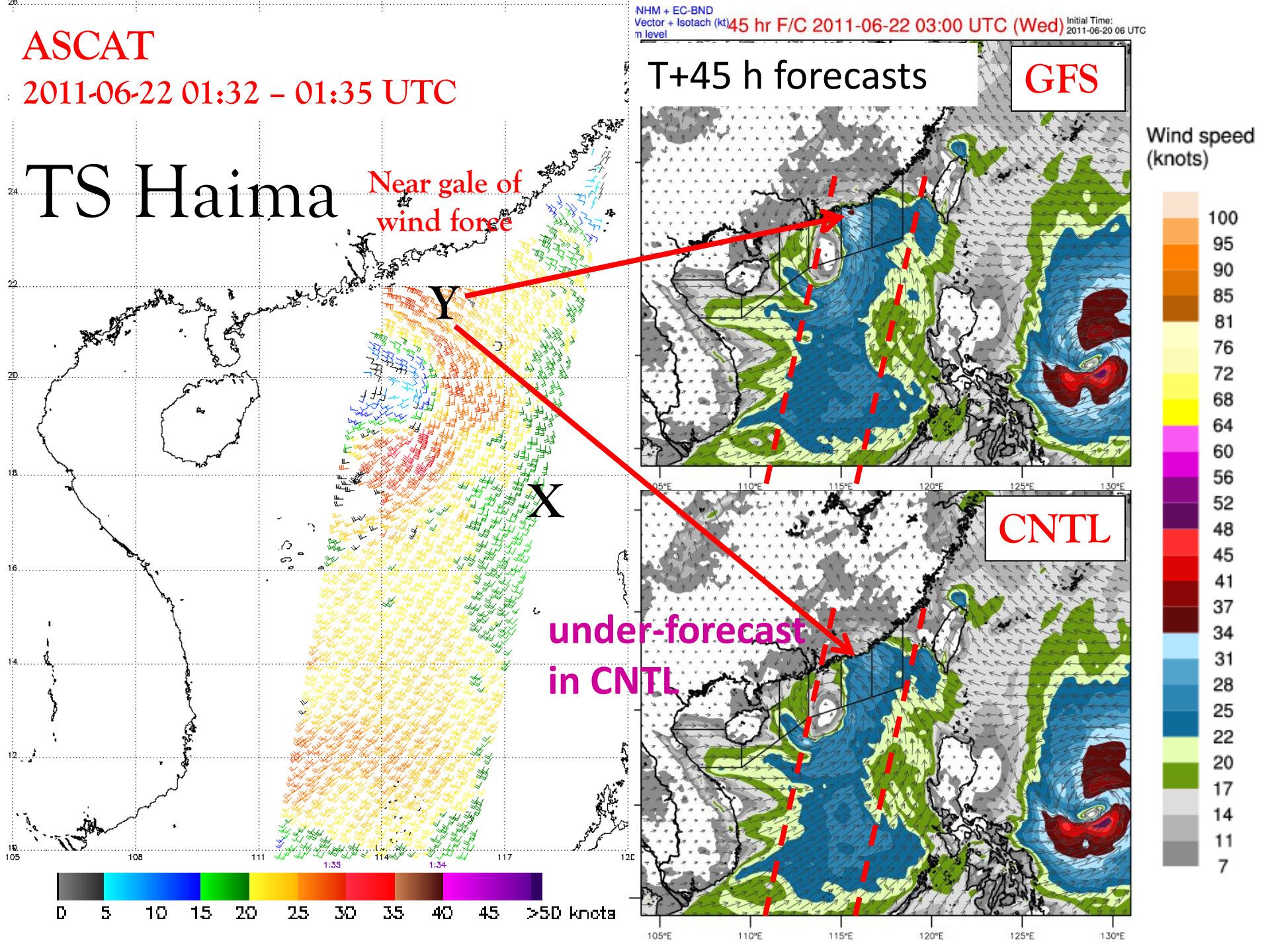
Recorded (red) and forecast (box-and-whisker) hourly average rainfall over the territory




(a)
24°N
22°N
20°N
18°N
16°N
110°E
112°E
114°E
116°E
118°E
Hong Kong
HKFIR
(b)
Hong Kong
Search And Rescue
Operation
T. Molave
2009-07-18 07:00-11:30 UTC
(c)
Hong Kong
T.S. Haima
2011-06-20 02:00-05:30 UTC
(d)
Hong Kong
T.S. Haima
2011-06-22 01:30-05:20 UTC
(e)
Hong Kong
T. Nesat
2011-09-28 02:40-06:50 UTC

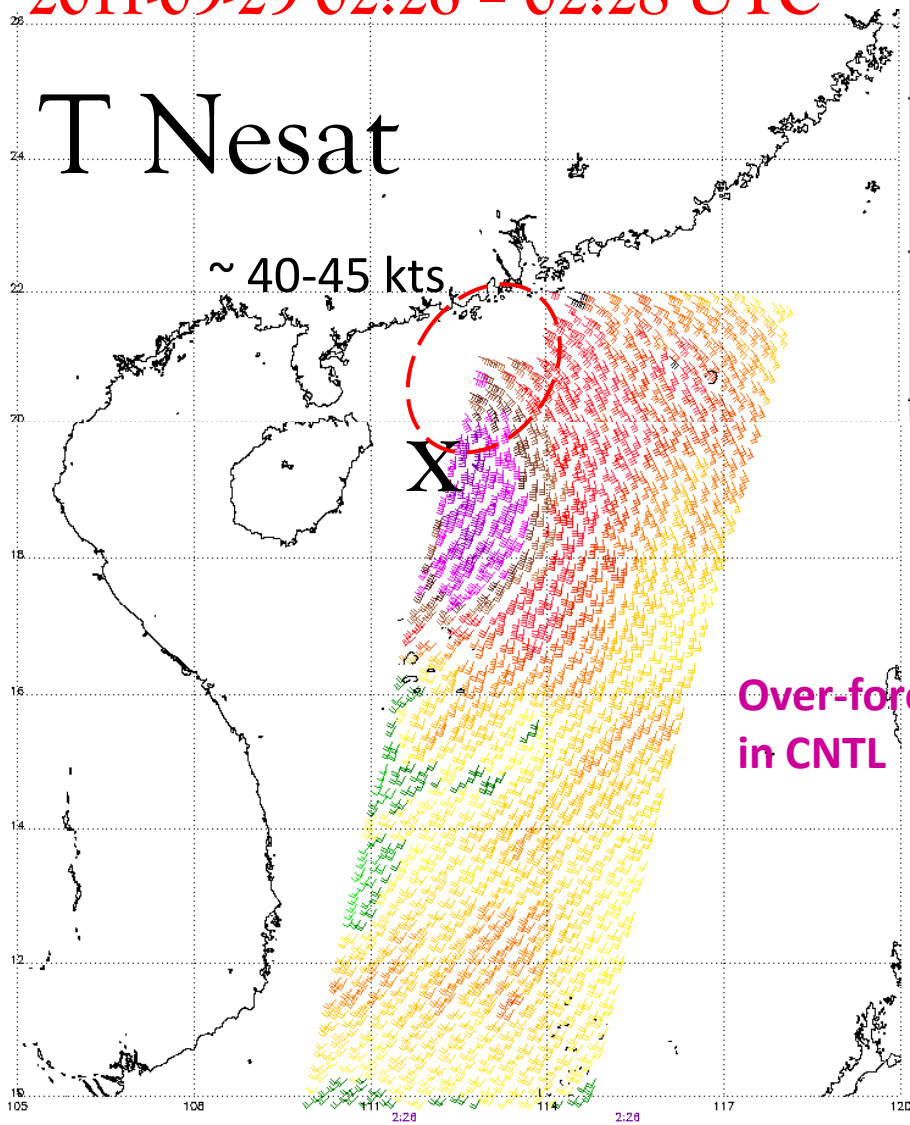
Reconnaissance Flight for *Molave* (2009)



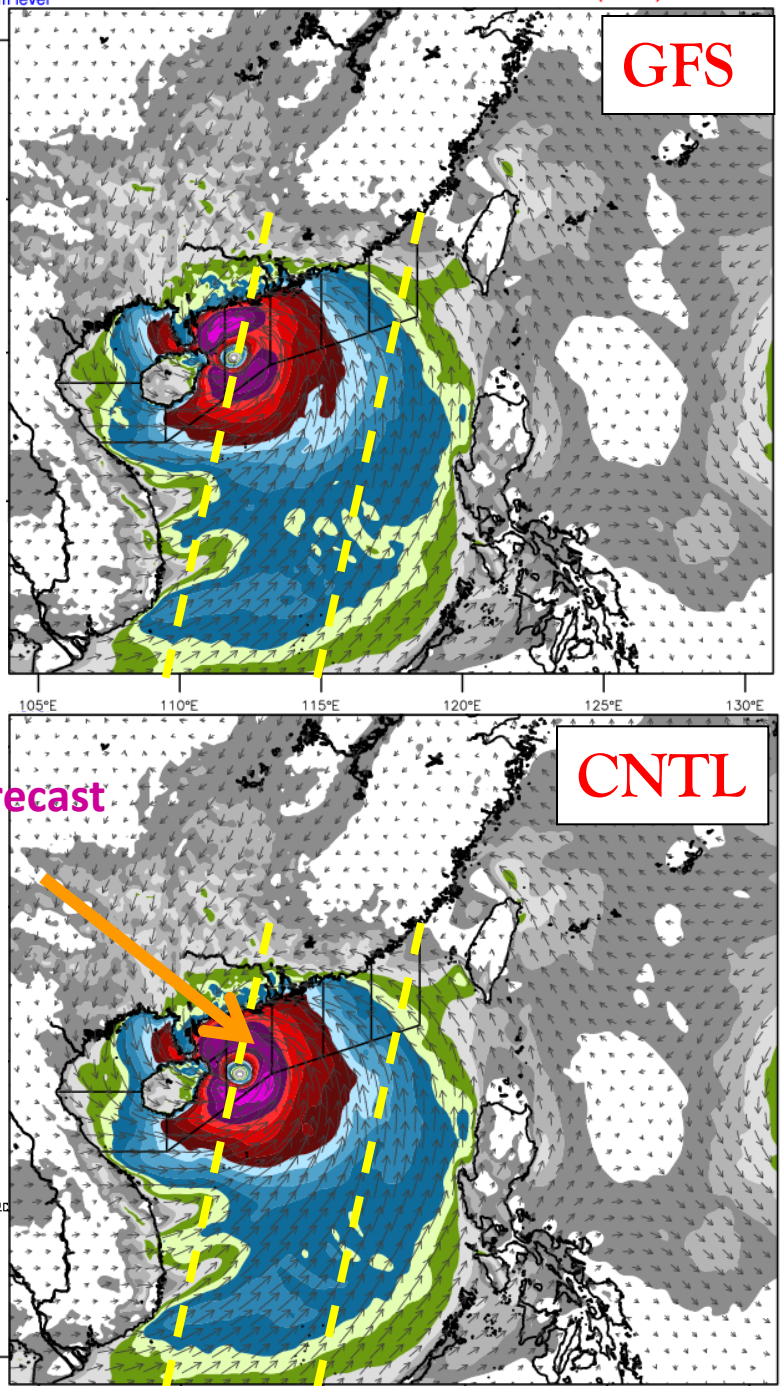

ASCAT
2011-06-22 01:32 – 01:35 UTC
TS Haima
Near gale of wind force
Y
X
under-forecast in CNTL
T+45 h forecasts
GFS
CNTL
NHM + EC-BND
Vector + Isotach (kt)
m level
45 hr F/C 2011-06-22 03:00 UTC (Wed)
Initial Time: 2011-06-20 06 UTC
Wind speed (knots)
100
95
90
85
81
76
72
68
64
60
56
52
48
45
41
37
34
31
28
25
22
20
17
14
11
7
0 5 10 15 20 25 30 35 40 45 >50 knots

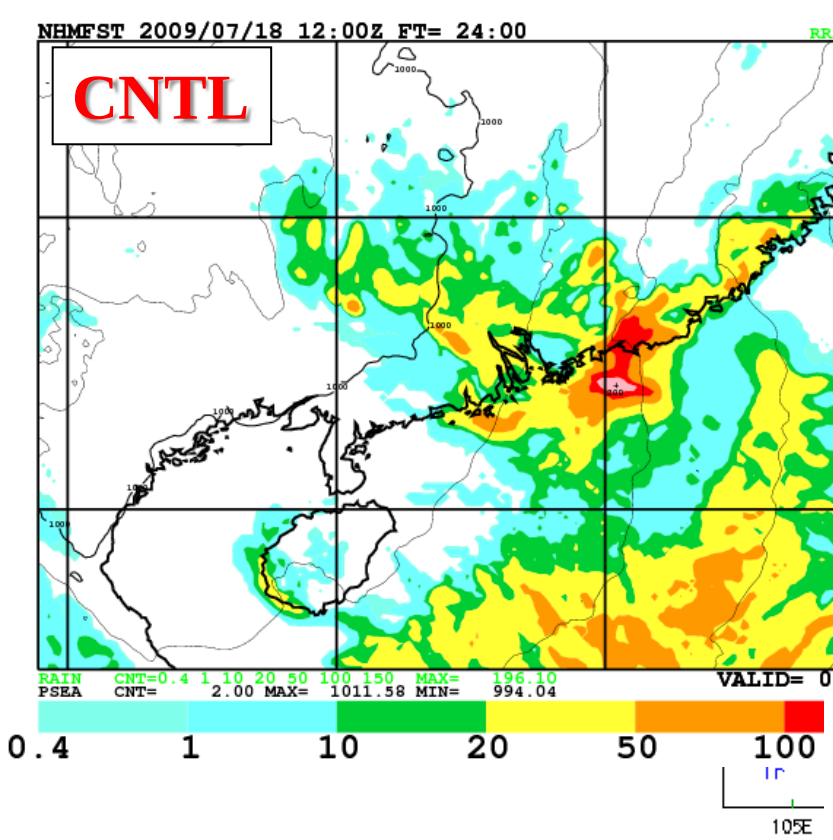
ASCAT

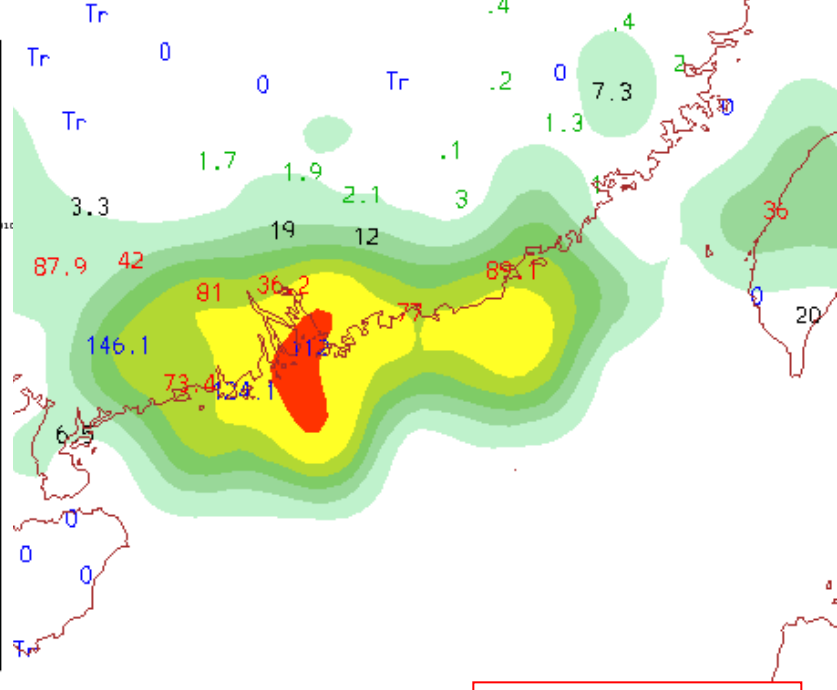
2011-09-29 02:26 – 02:28 UTC

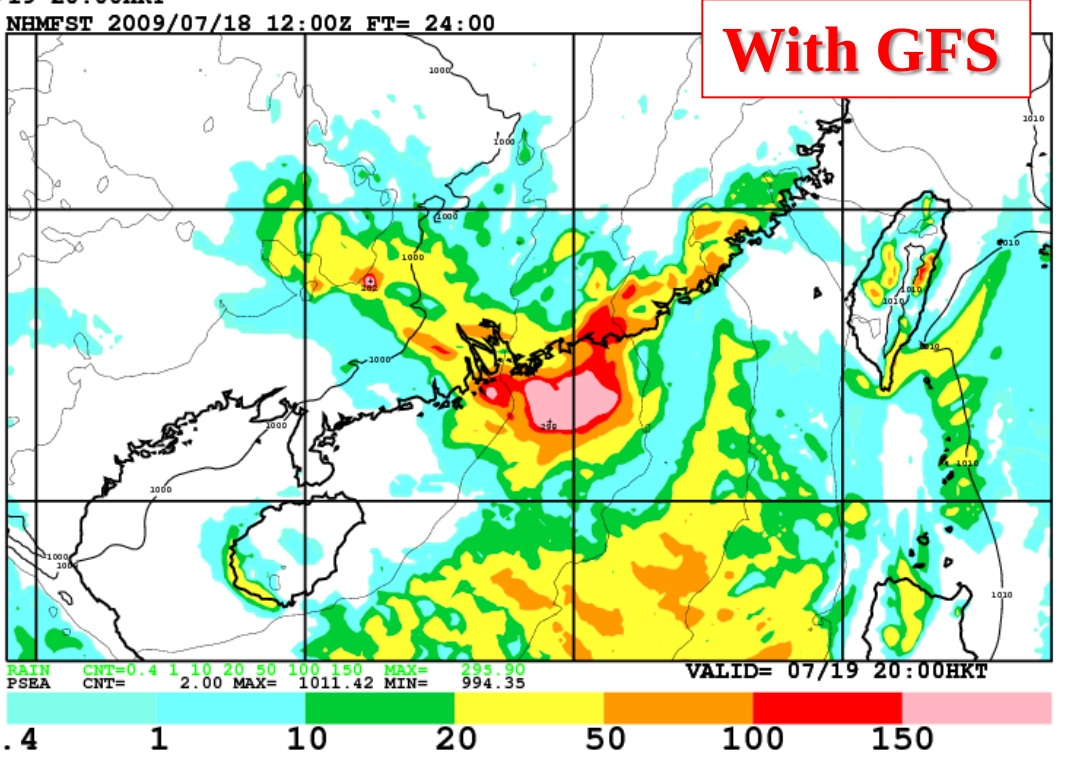


Over-forecast in CNTL



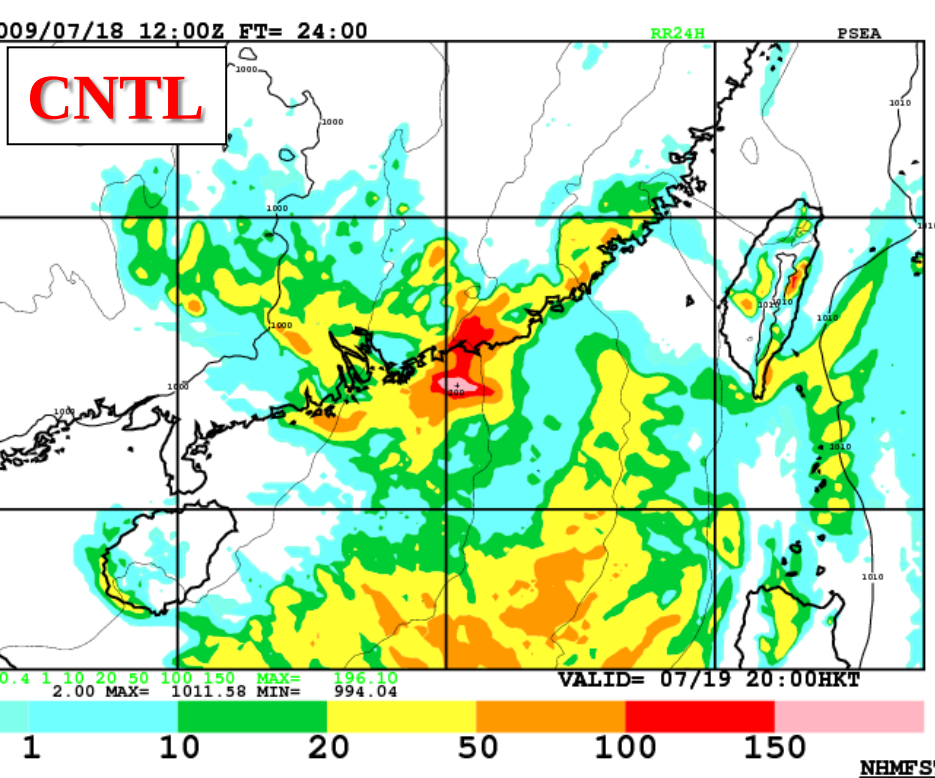


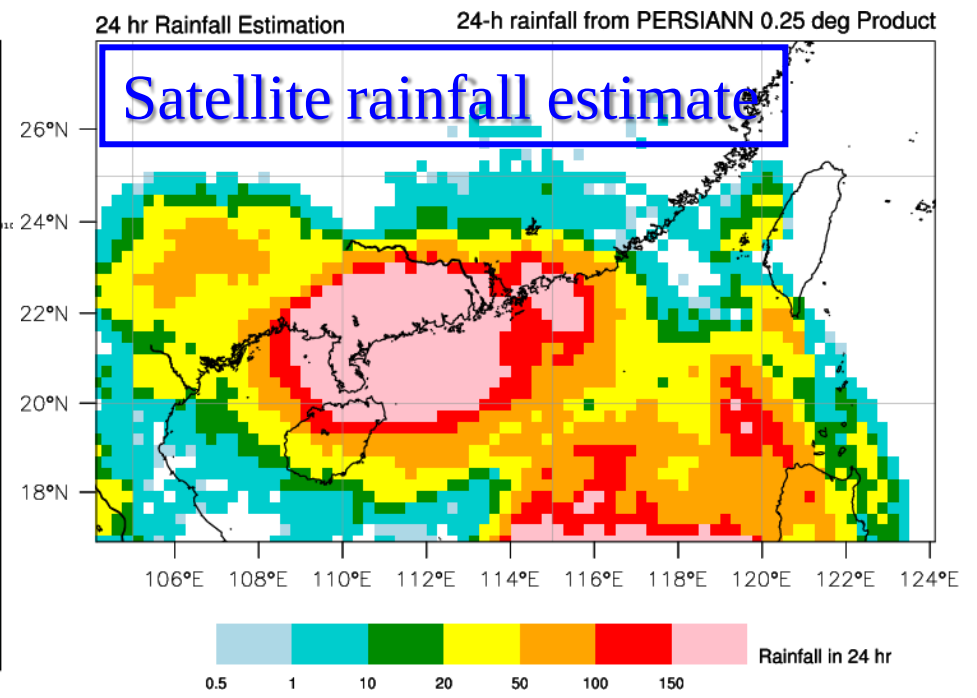


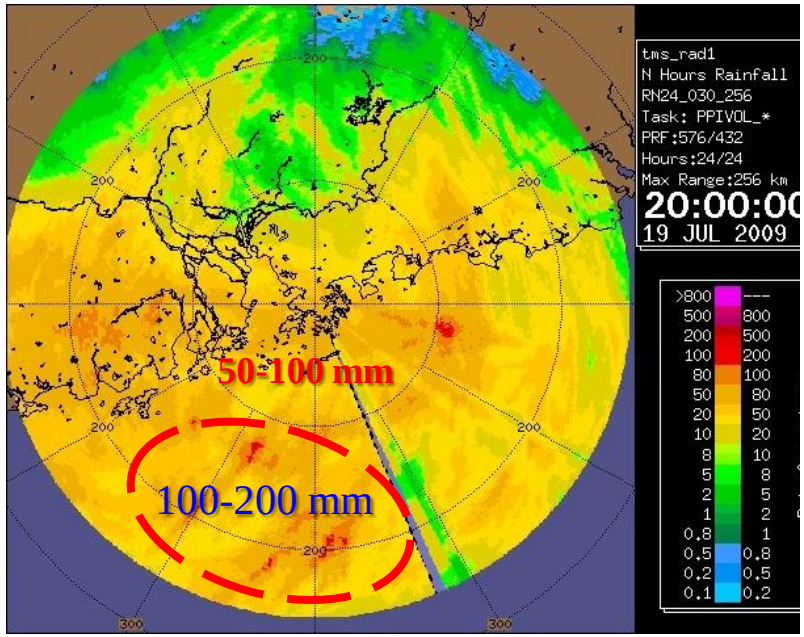


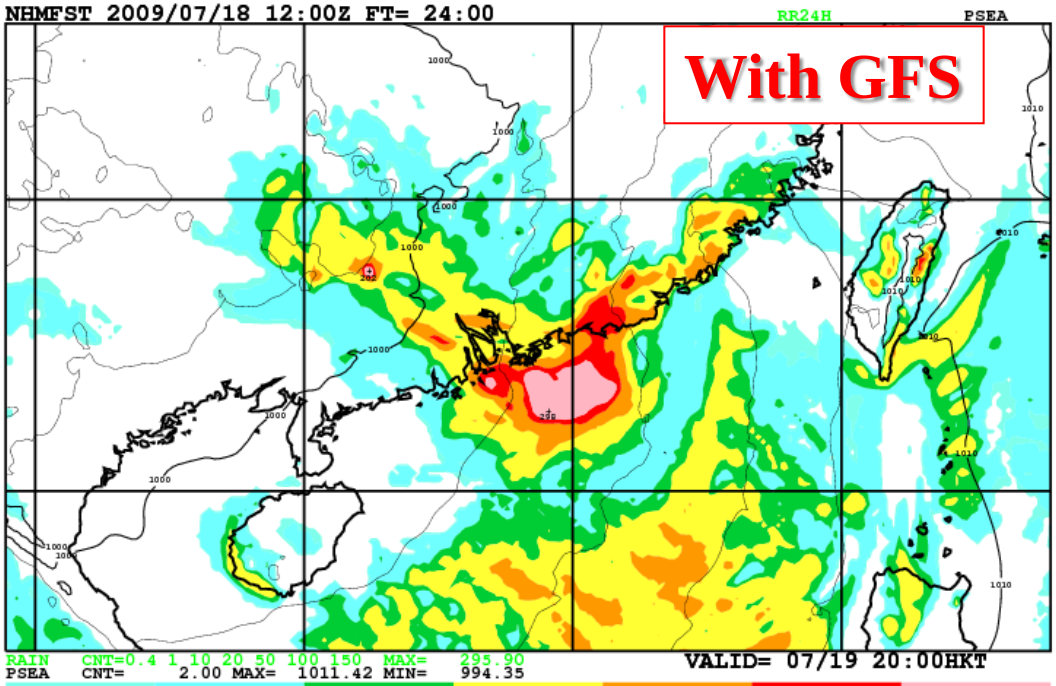
T. Molave

24-hr acc. rainfall

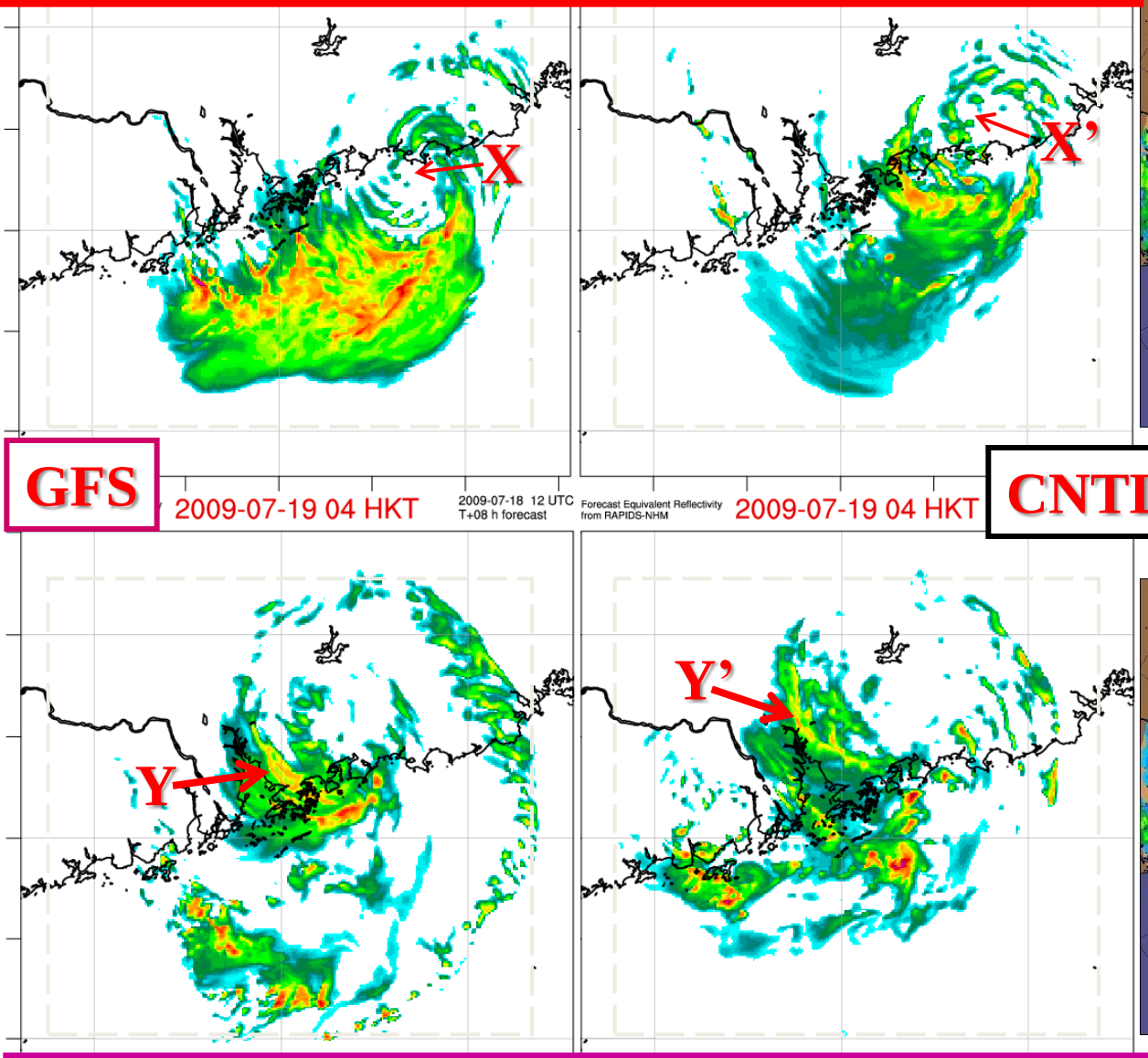

009/07/18 12:00Z FT= 24:00
RR24H
PSEA
CNTL
1000
1010
0.4 1 10 20 50 100 150 MAX= 196.10
2.00 MAX= 1011.58 MIN= 994.04
VALID= 07/19 20:00HKT
1
10
20
50
100
150

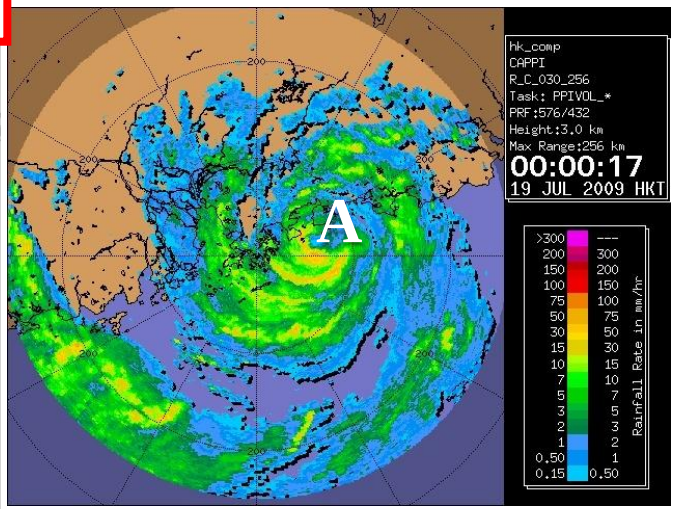

24 hr Rainfall Estimation
24-h rainfall from PERSIANN 0.25 deg Product
Satellite rainfall estimate
26°N
24°N
22°N
20°N
18°N
106°E
108°E
110°E
112°E
114°E
116°E
118°E
120°E
122°E
124°E
0.5
1
10
20
50
100
150
Rainfall in 24 hr

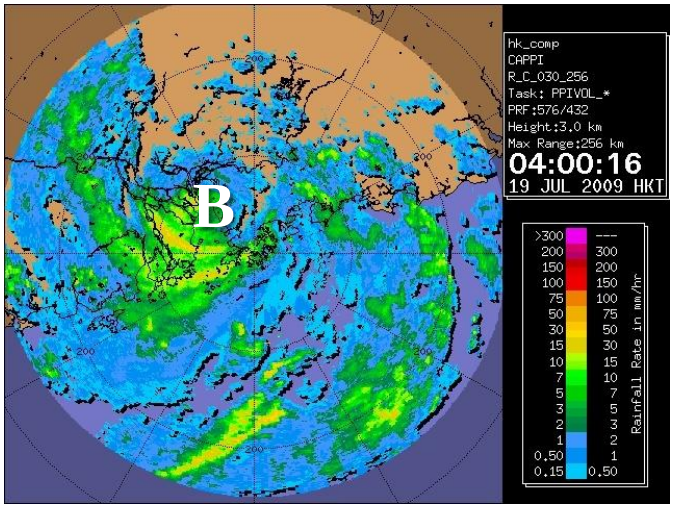

tms_rad1
N Hours Rainfall
RN24_030_256
Task: PPIVOL_*
PRF:576/432
Hours:24/24
Max Range:256 km
20:00:00
19 JUL 2009
>800
500
200
100
80
50
20
10
8
5
2
1
0.8
0.5
0.2
0.1
50-100 mm
100-200 mm


NHMFST 2009/07/18 12:00Z FT= 24:00
RR24H
PSEA
With GFS
RAIN CNT=0.4 1 10 20 50 100 150 MAX= 295.90
PSEA CNT= 2.00 MAX= 1011.42 MIN= 994.35
VALID= 07/19 20:00HKT

Forecasts from RAPIDS-NHM (**T+4h** from model run at 12 UTC 18 July 2009)

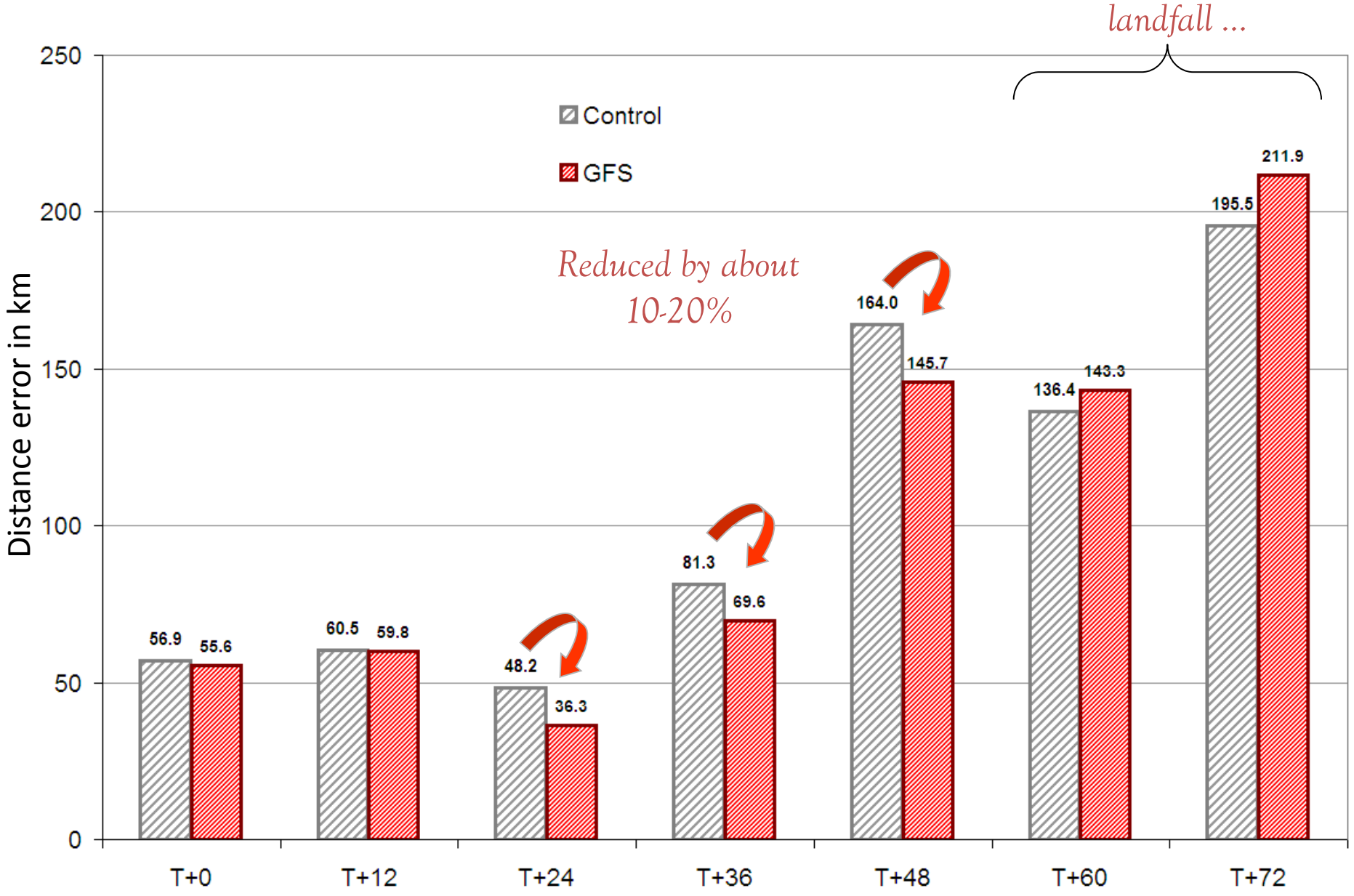




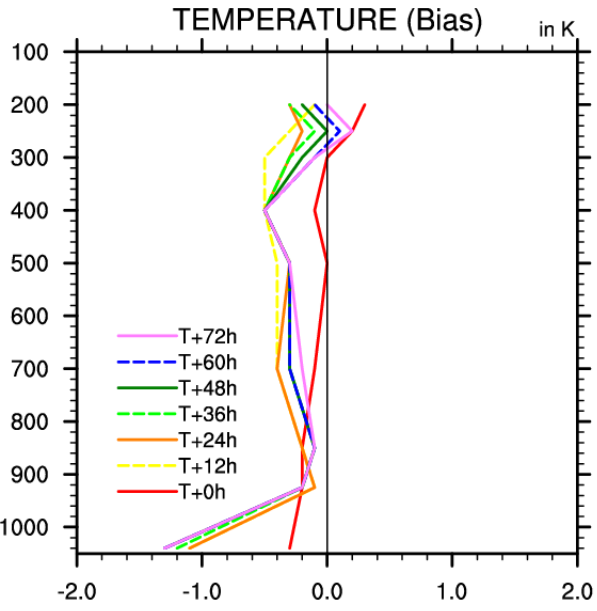


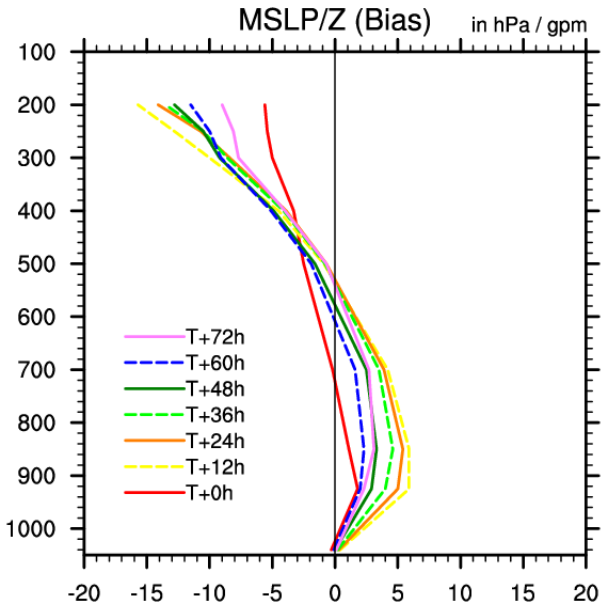
Forecasts from RAPIDS-NHM (**T+8h** from model run at 12 UTC 18 July 2009)

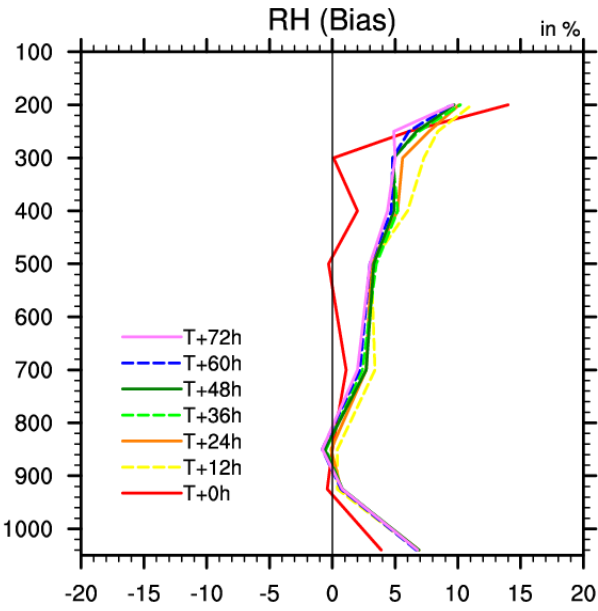
Forecast Track Error

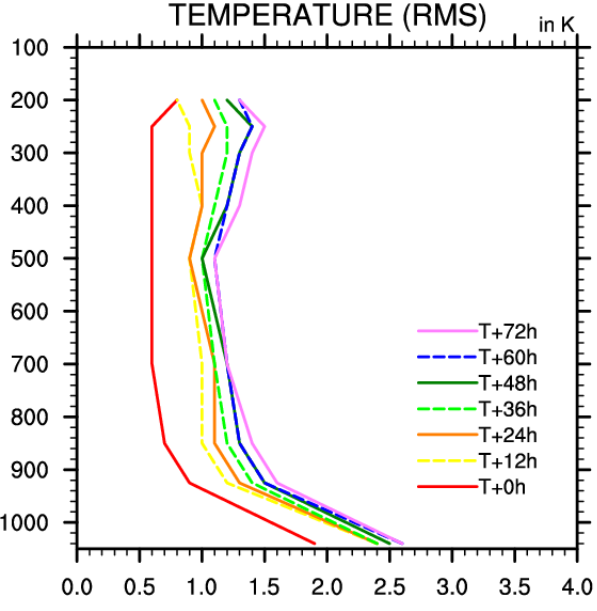


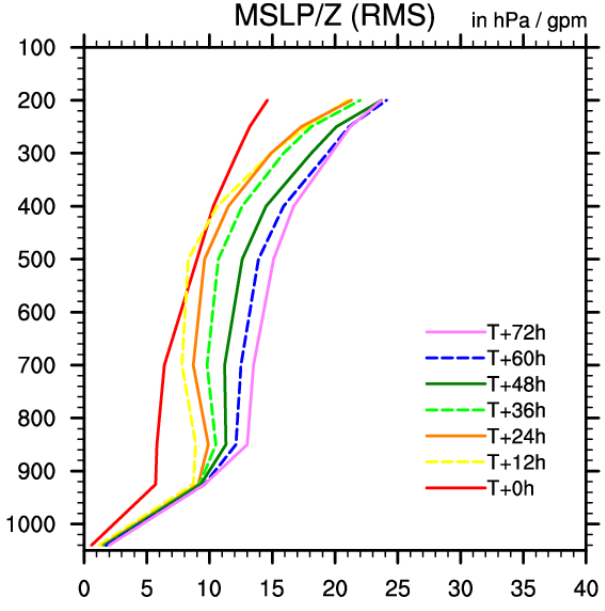
Vertical profiles of Meso-NHM analysis and forecast RMSE in AUG 2013

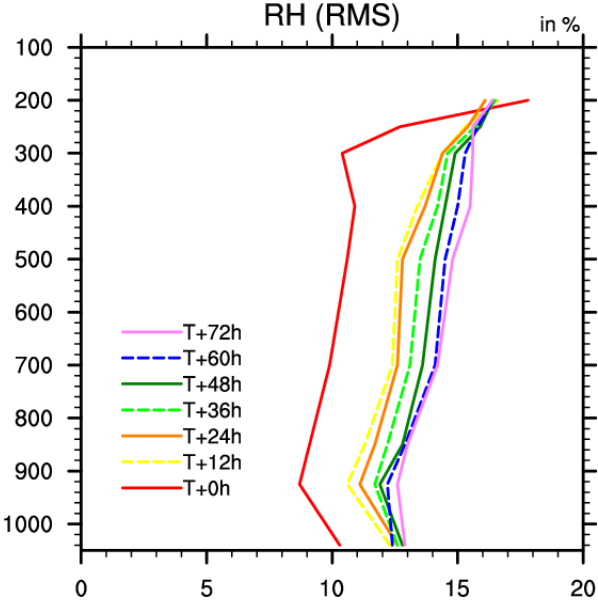




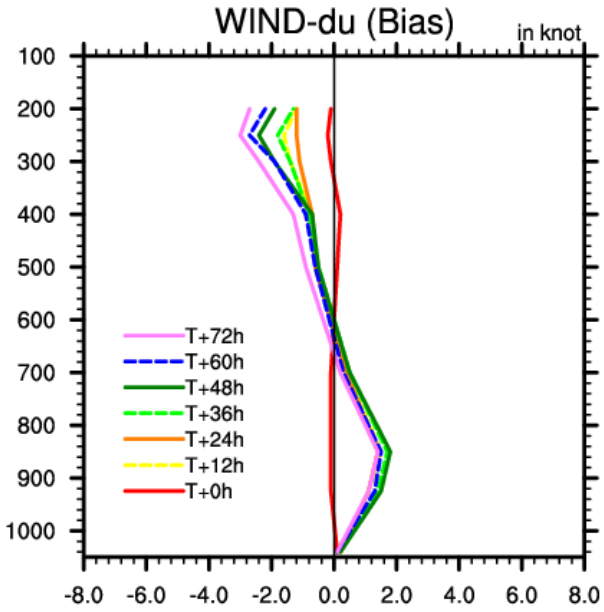


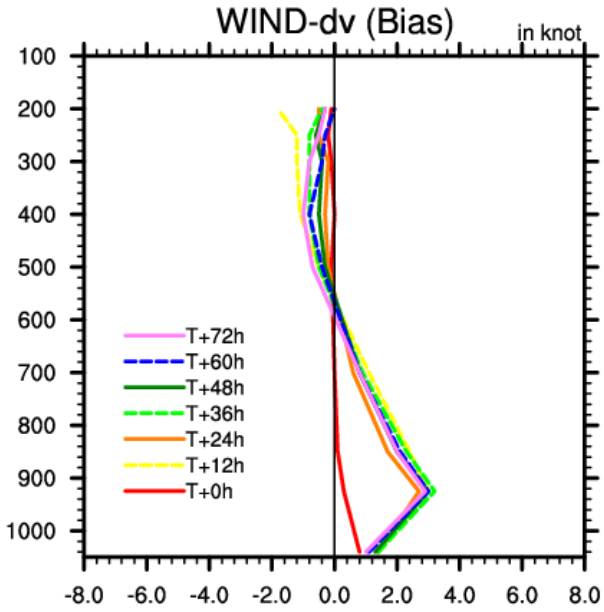


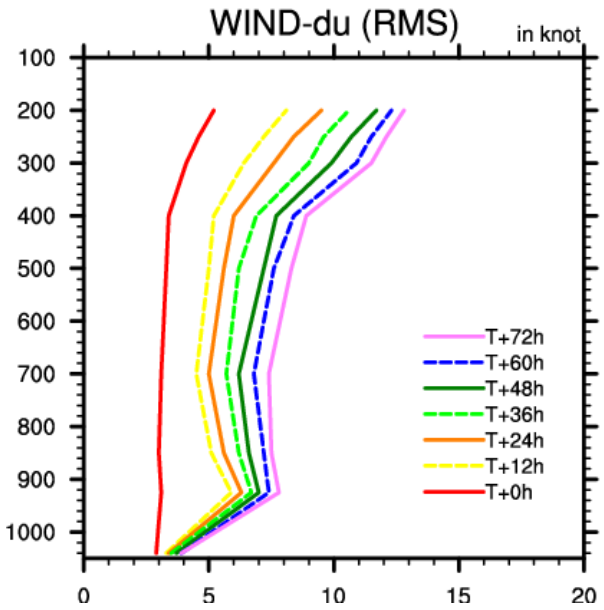


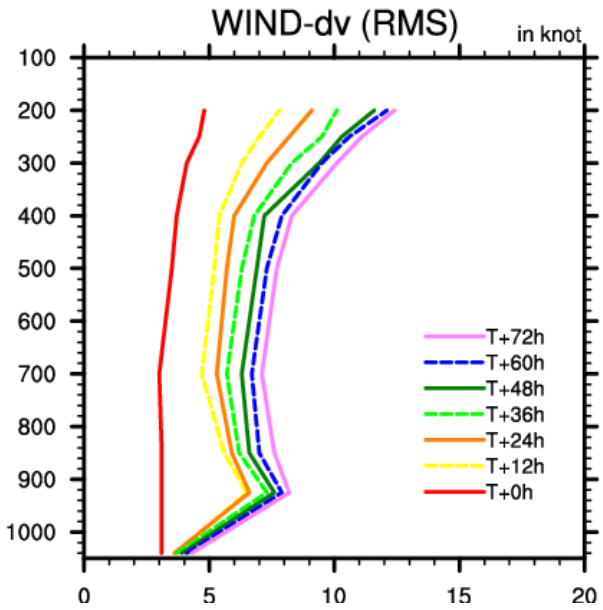


Vertical profiles of Meso-NHM analysis and forecast RMSE in AUG 2013

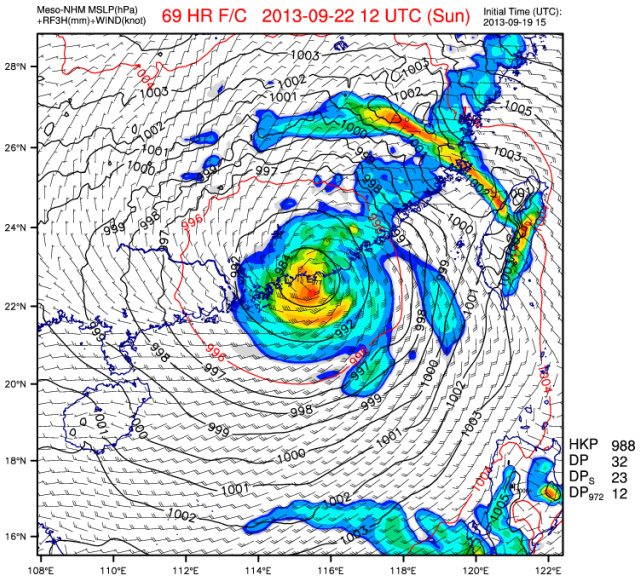


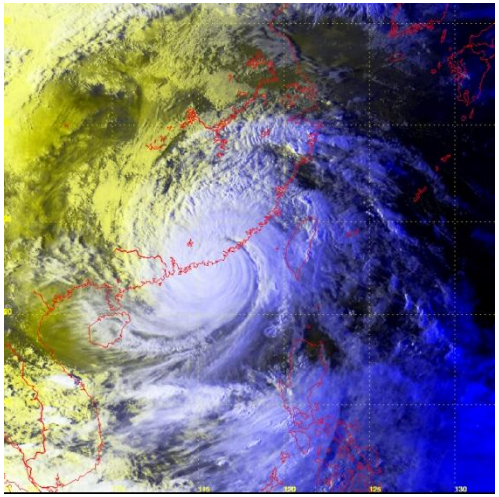


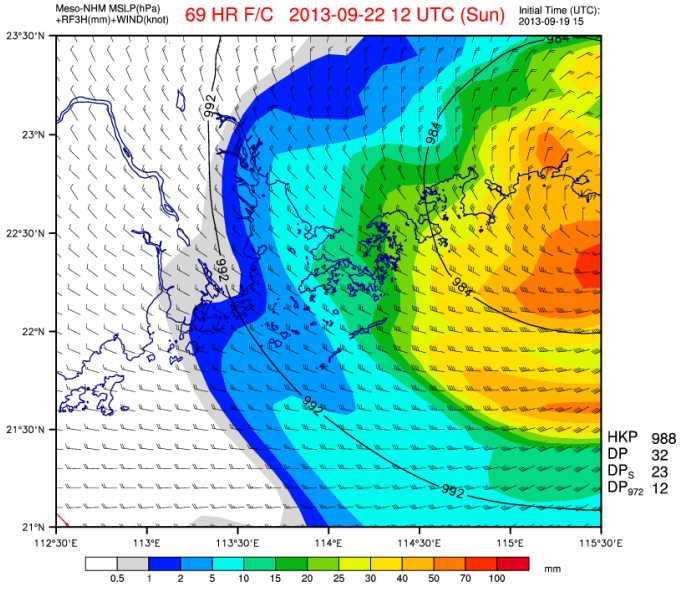


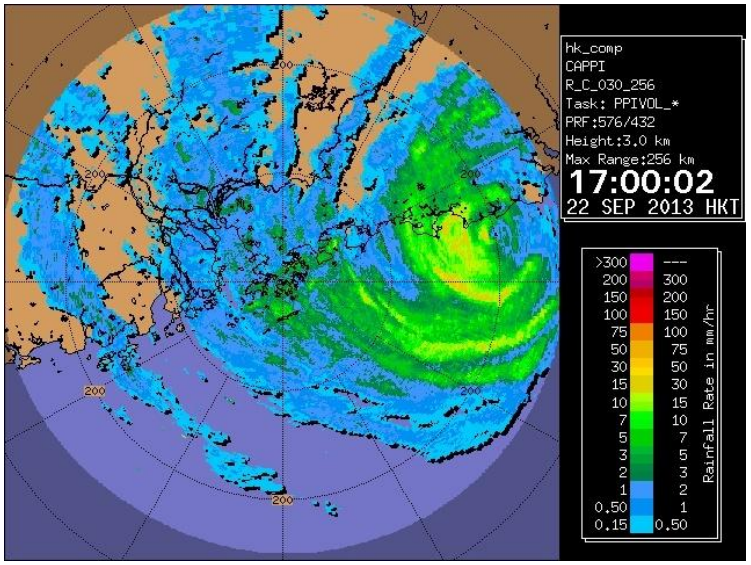


Super Typhoon Usagi (1319)

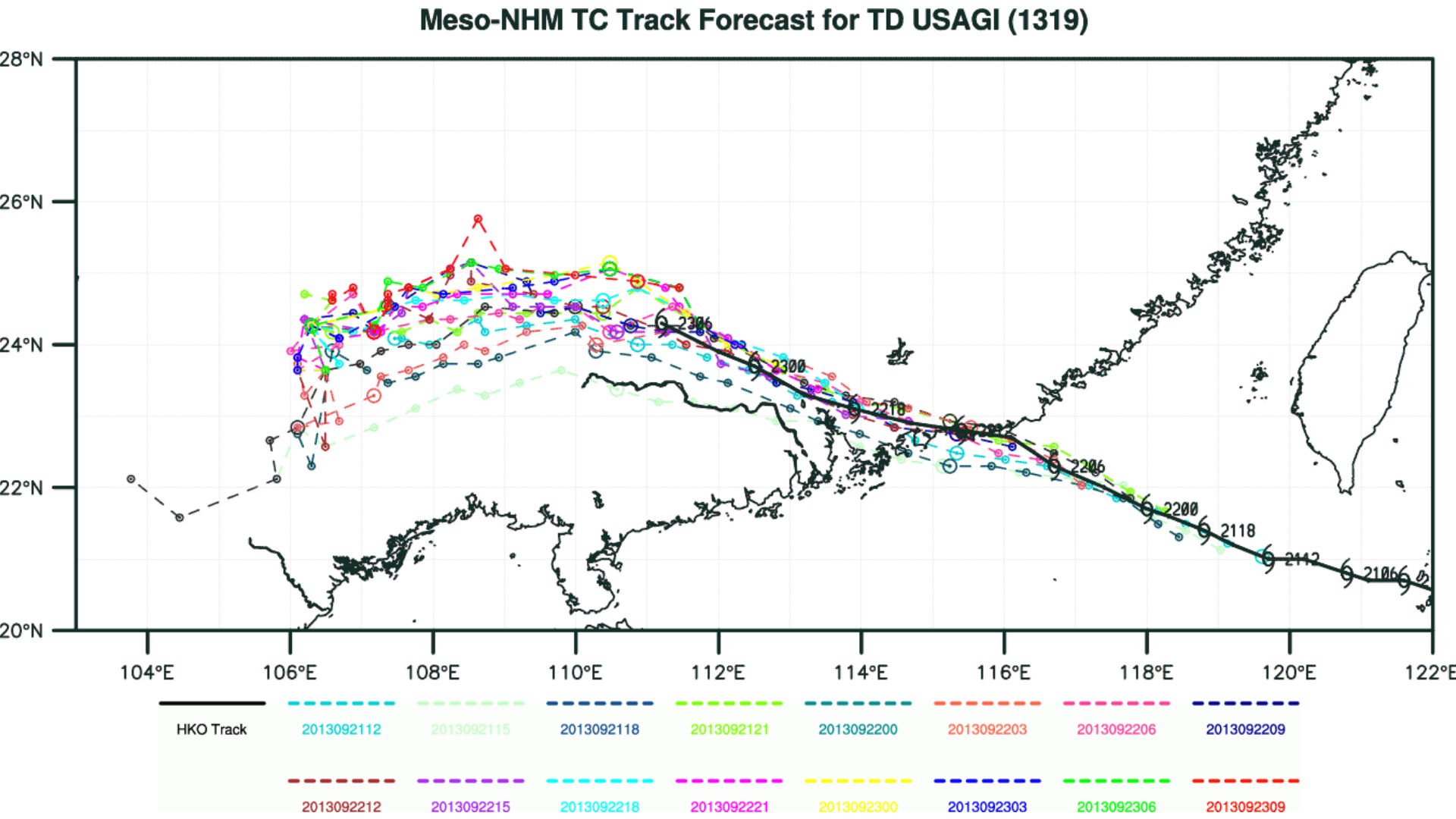








Super Typhoon Usagi (1319)



Looking Ahead – AIR-NHM

- Expansion of computational power to support extended domain of Meso-NHM

- Assimilation of local radar data and regional composites into Meso-NHM

- Assimilation of TC reconnaissance flight data on an operational basis

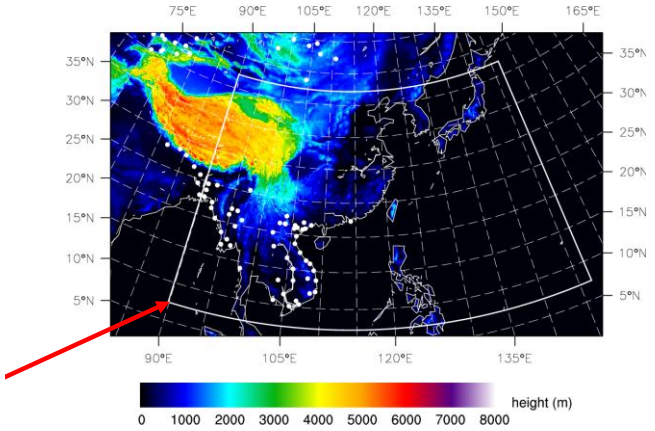
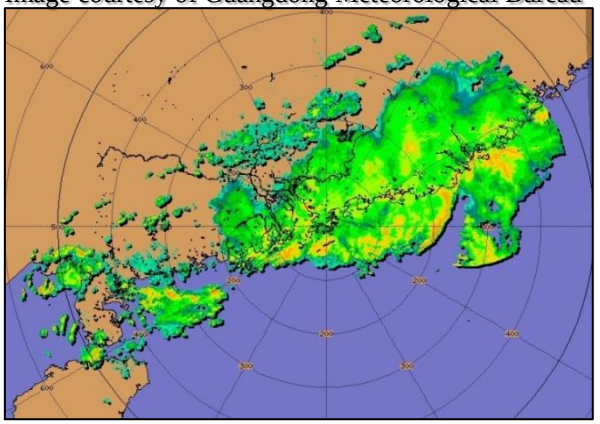


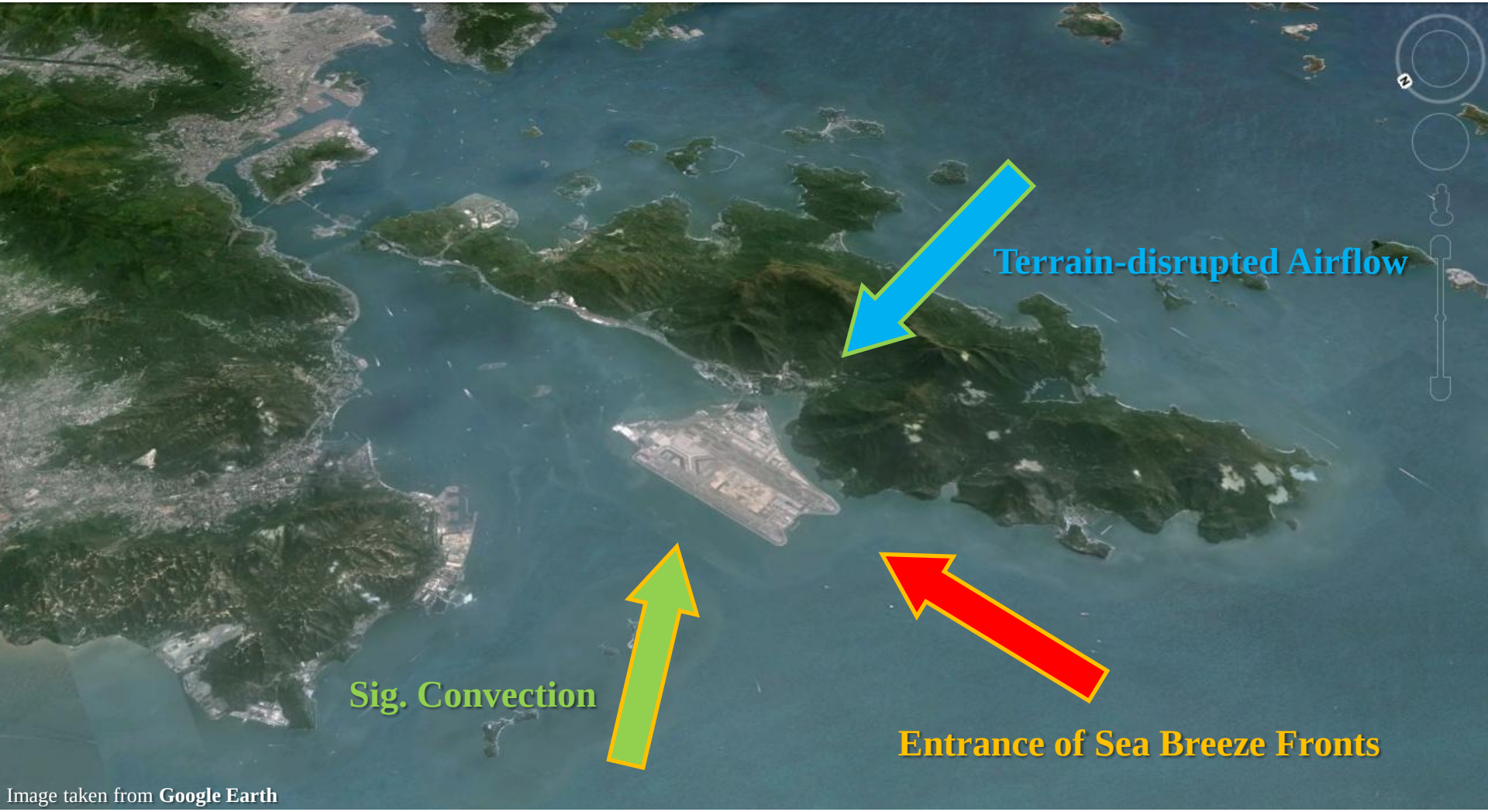
Image courtesy of Guangdong Meteorological Bureau



HKO-AVM – the Aviation Model

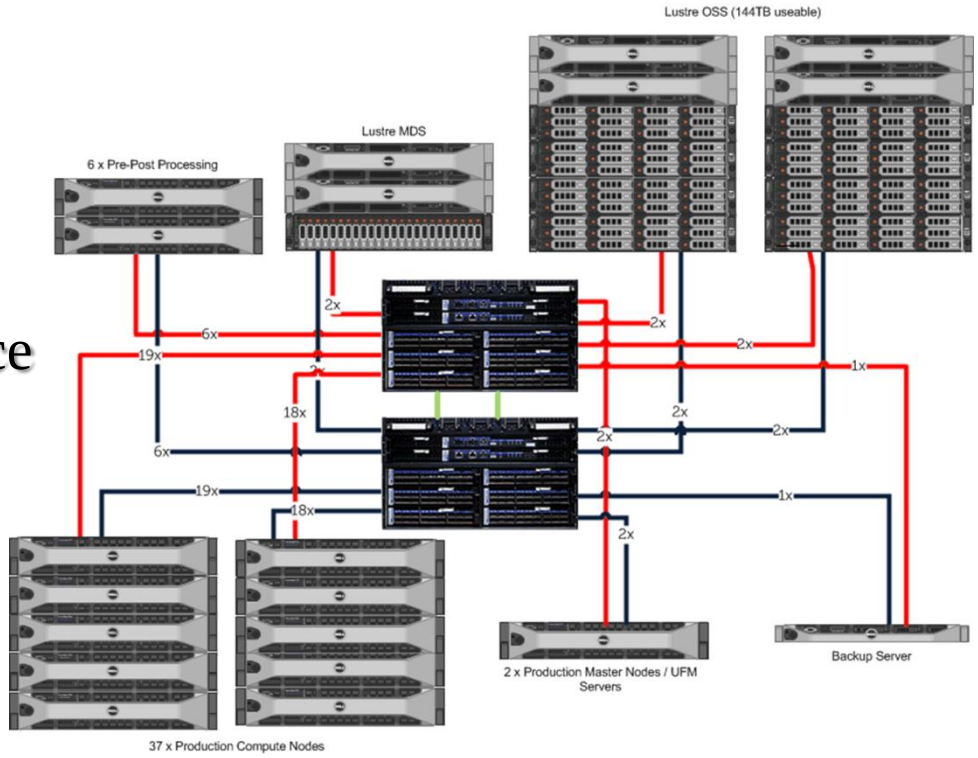
Image taken from **Google Earth**

HKO-AVM – the Aviation Model



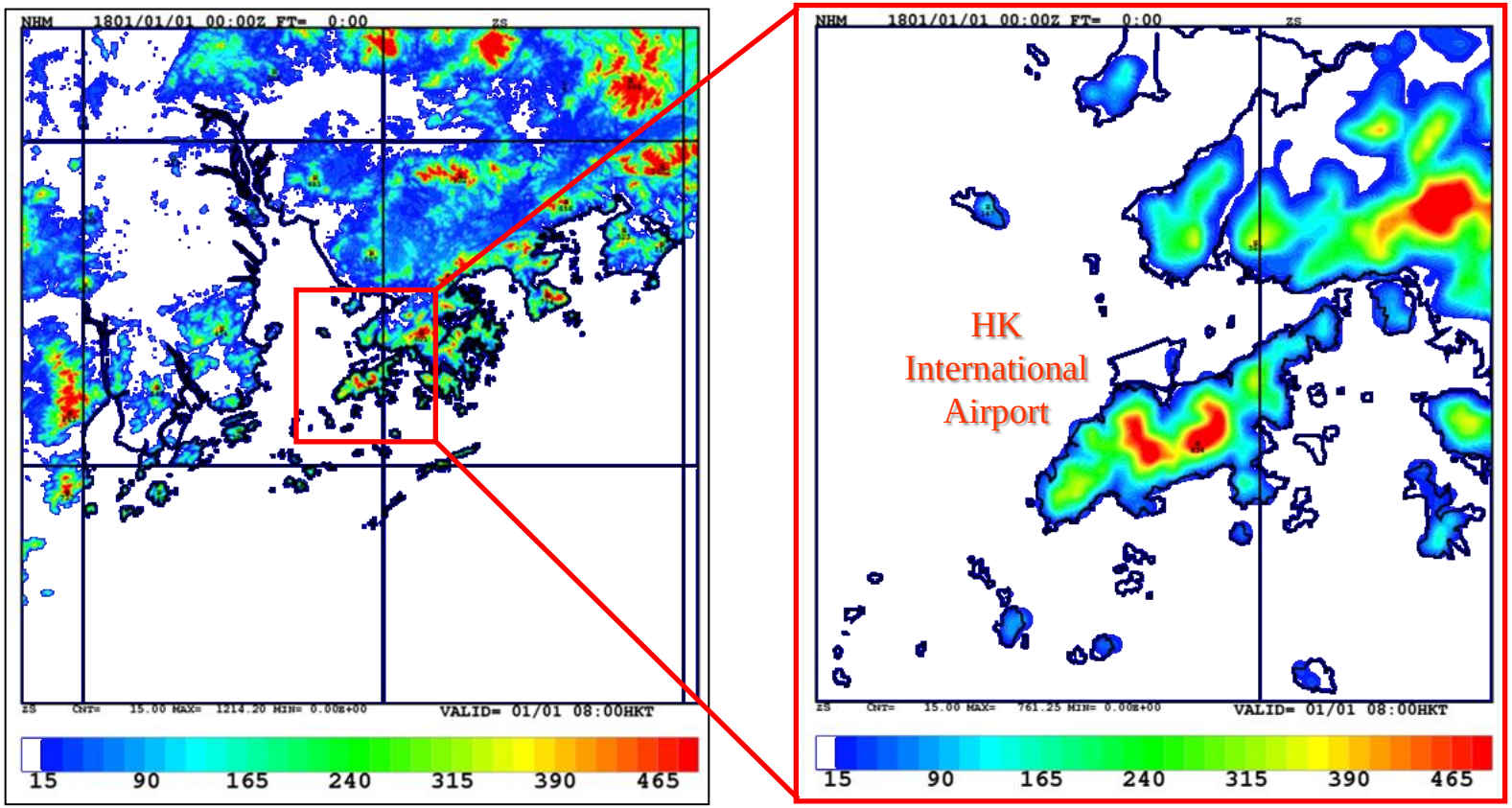
HKO-AVM – the Aviation Model

- Fine-resolution NWP system devised to:
  - Meet emerging needs of the aviation community
  - Provide enhanced aviation-specific forecast products
- Hardware:
  - Linux cluster comprising computation & pre/post-processing nodes
  - 12 TFlop peak performance
- Software:
  - Based on WRF-ARW (v3.4.1 / v3.5)

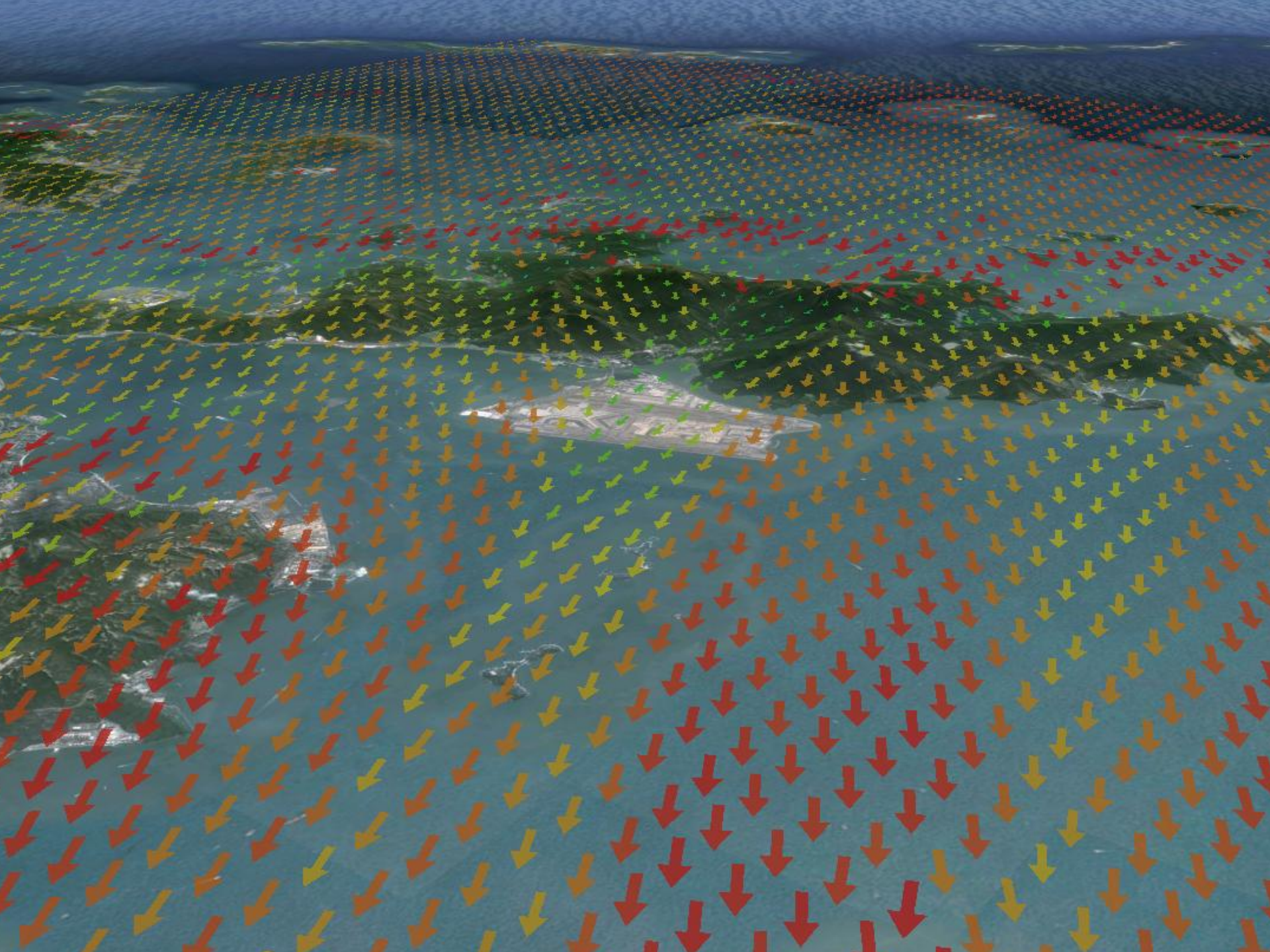


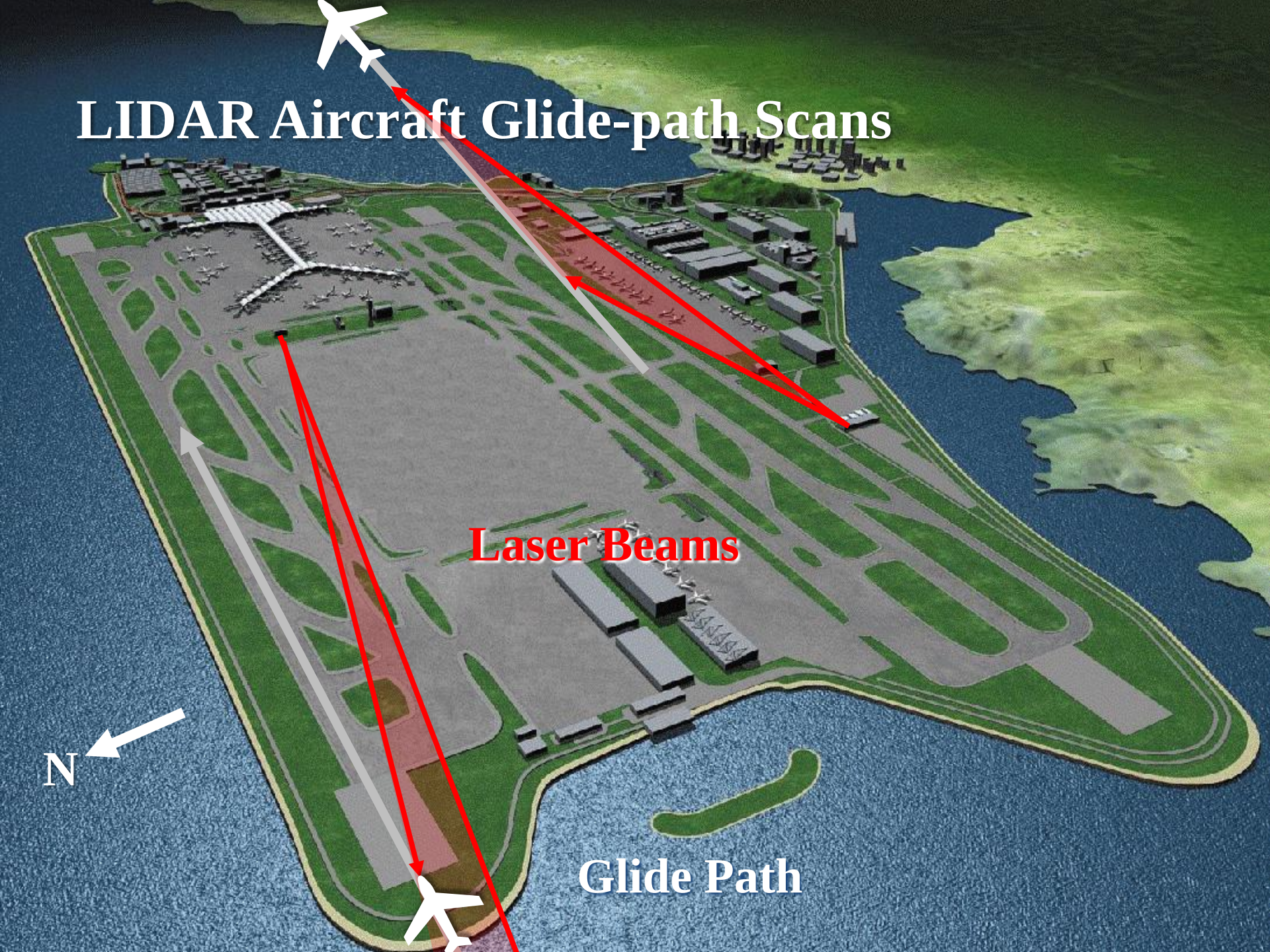
Pearl River Delta (PRD) domain
dx = 600 m
Forecast range = 6 - 9 hr

HK Airport (HKA) domain
dx = 200 m
Forecast range = 6 - 9 hr

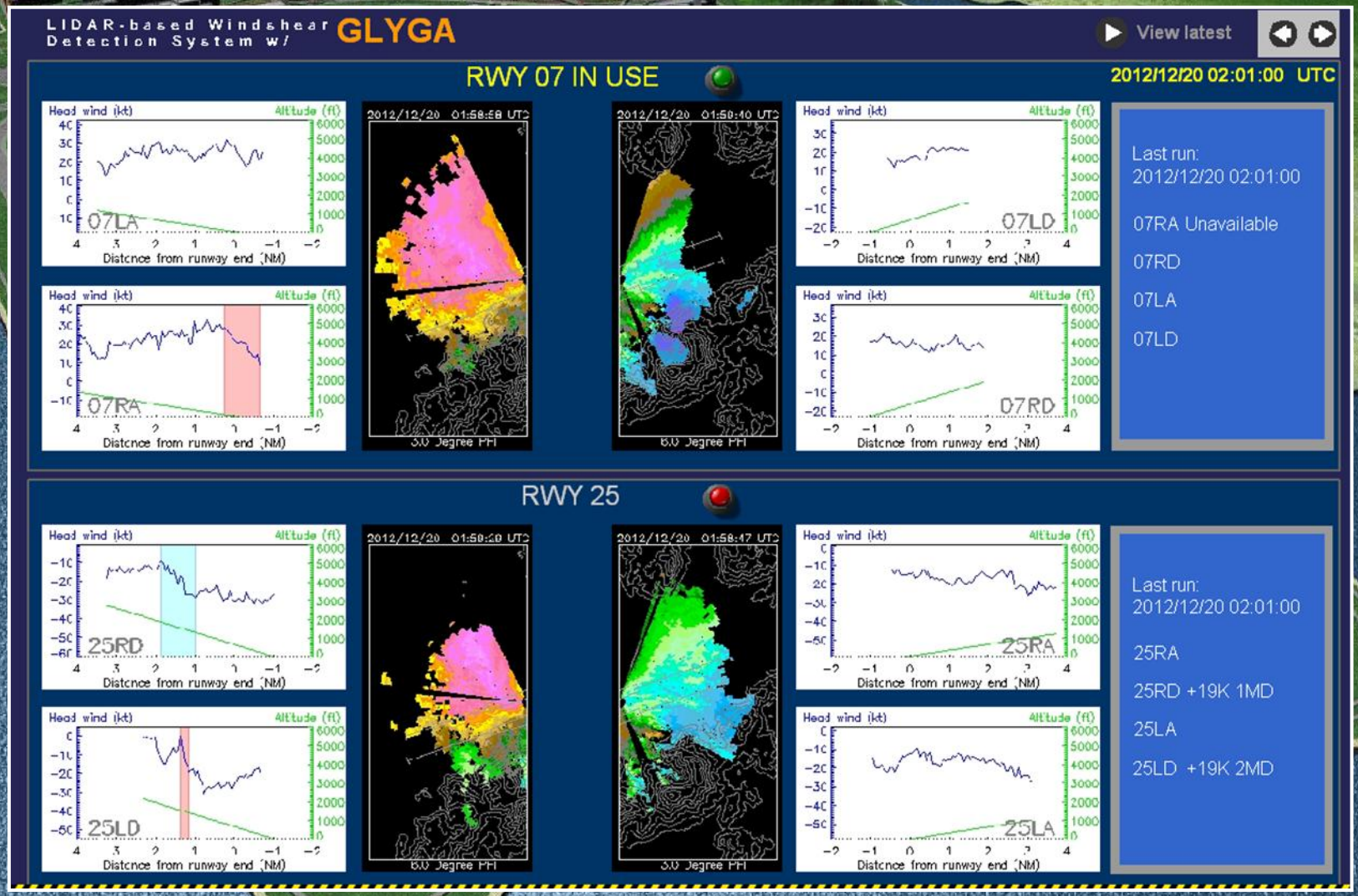


- Hourly-updated forecasts up to 6 – 9 hours ahead
- Initial/boundary conditions: RAPIDS-NHM (2 km)
- Inner domain: 1- or 2-way nesting

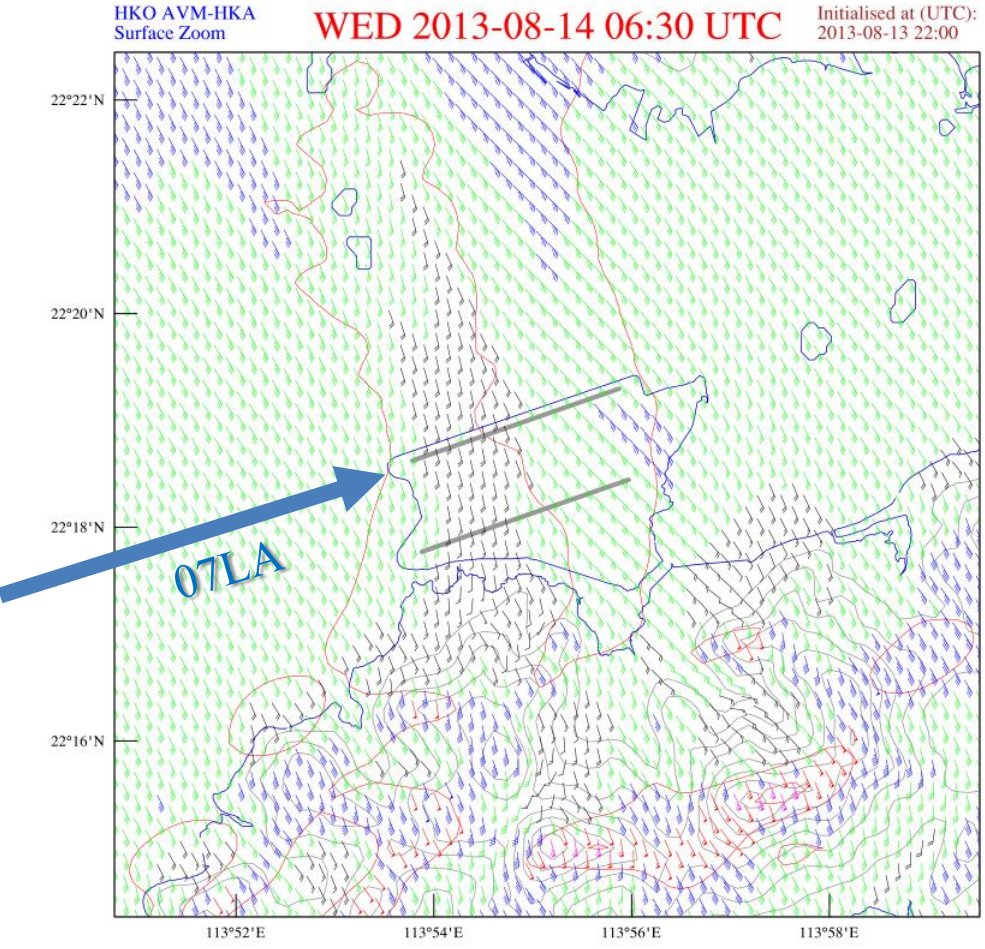


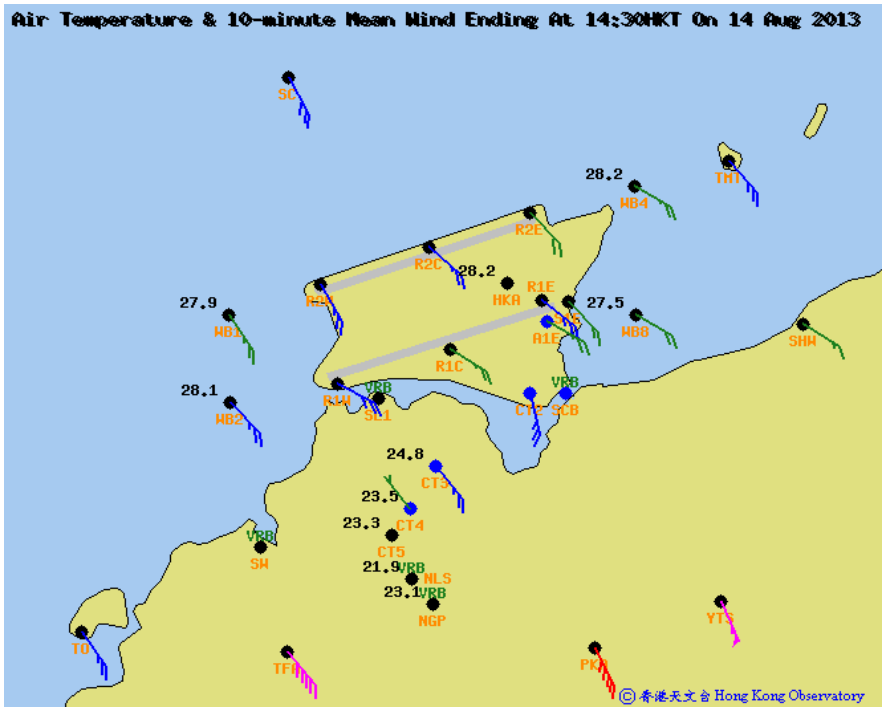

LIDAR Aircraft Glide-path Scans
Laser Beams
N
Glide Path

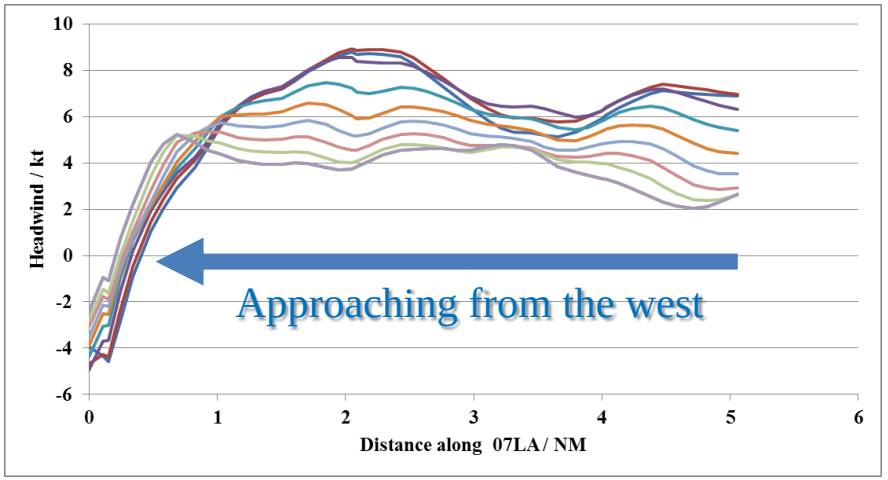
LIDAR Aircraft Glide-path Scans



SuperT. *UTOR* (2013)



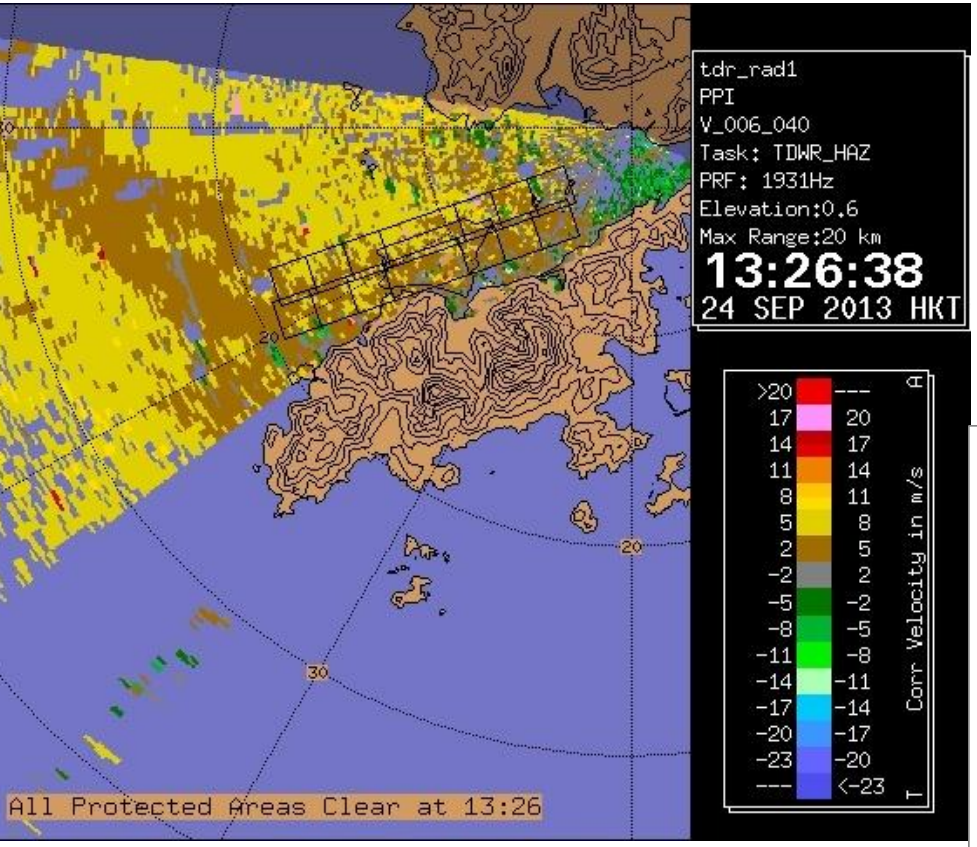




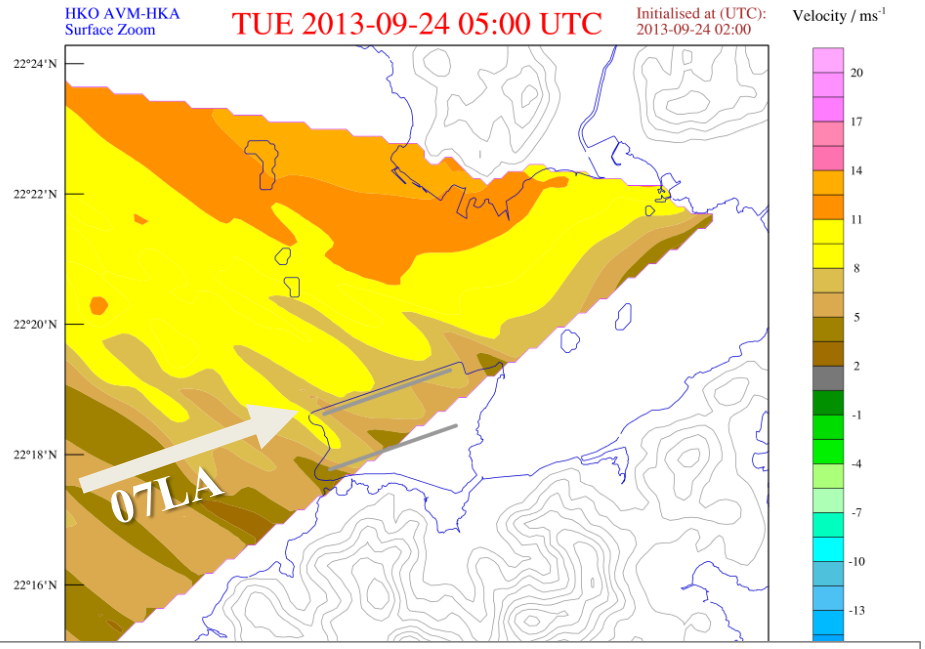
Terrain-induced Windshear Event

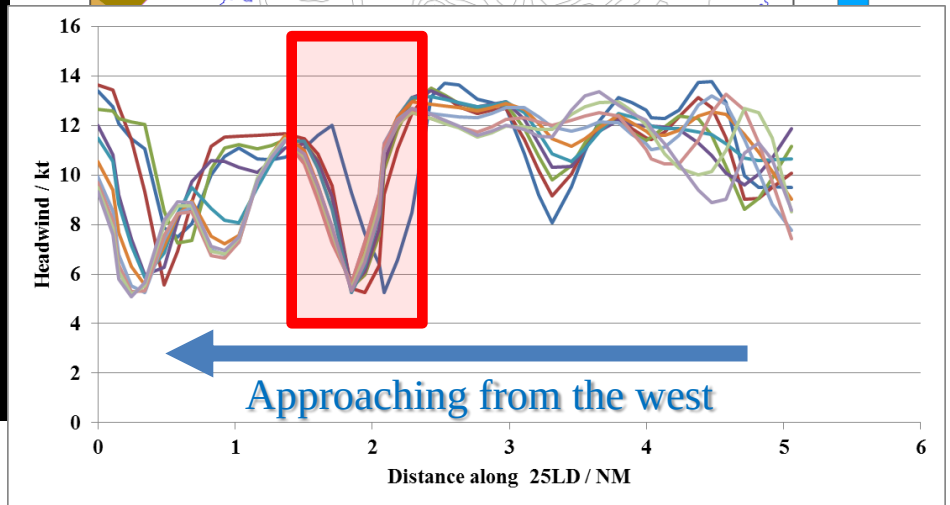
Pilot Report of Significant Windshear:
2013-09-24 05:26 UTC, 07LA, WS -15 kt

TDWR 0.6-deg Doppler Velocity PPI

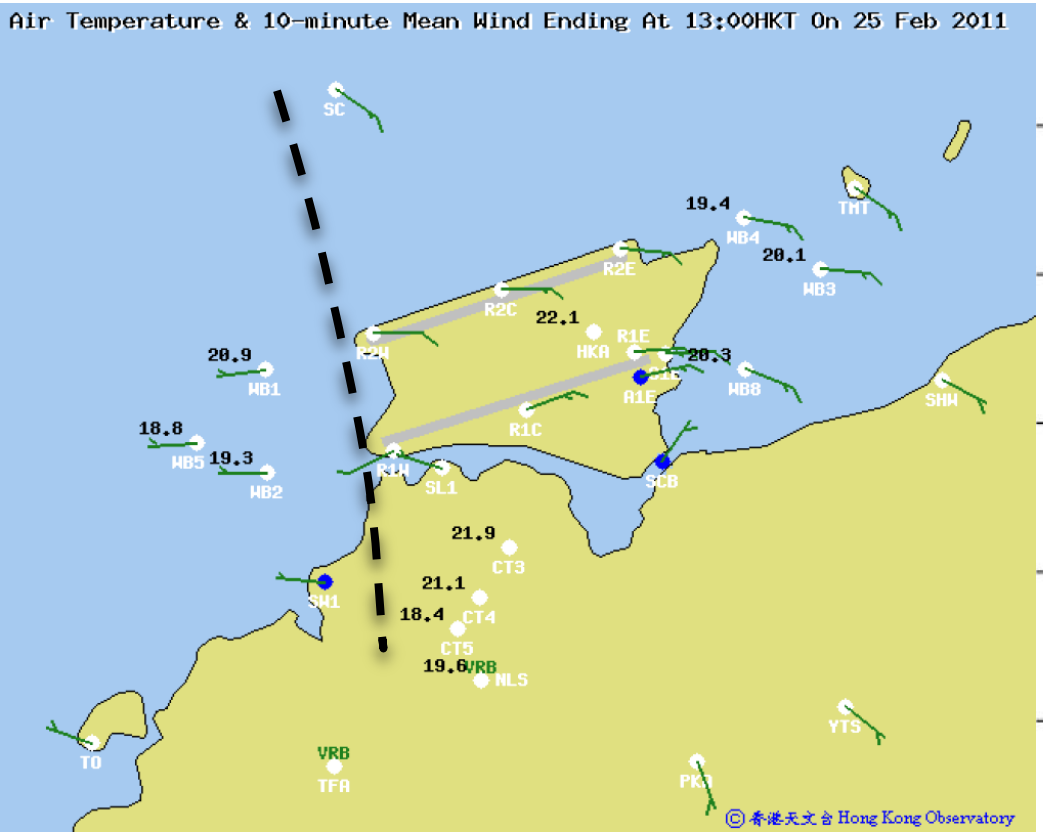


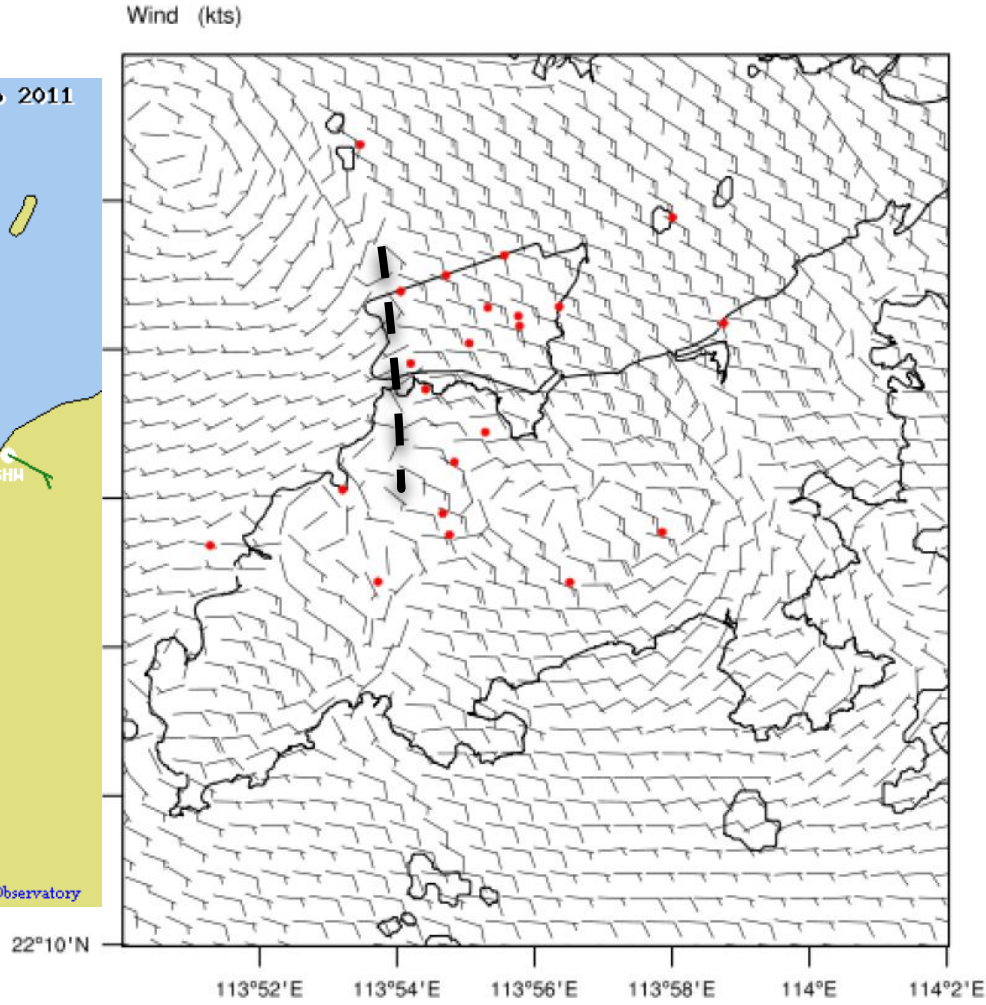
Simulated TDWR Doppler Velocity PPI



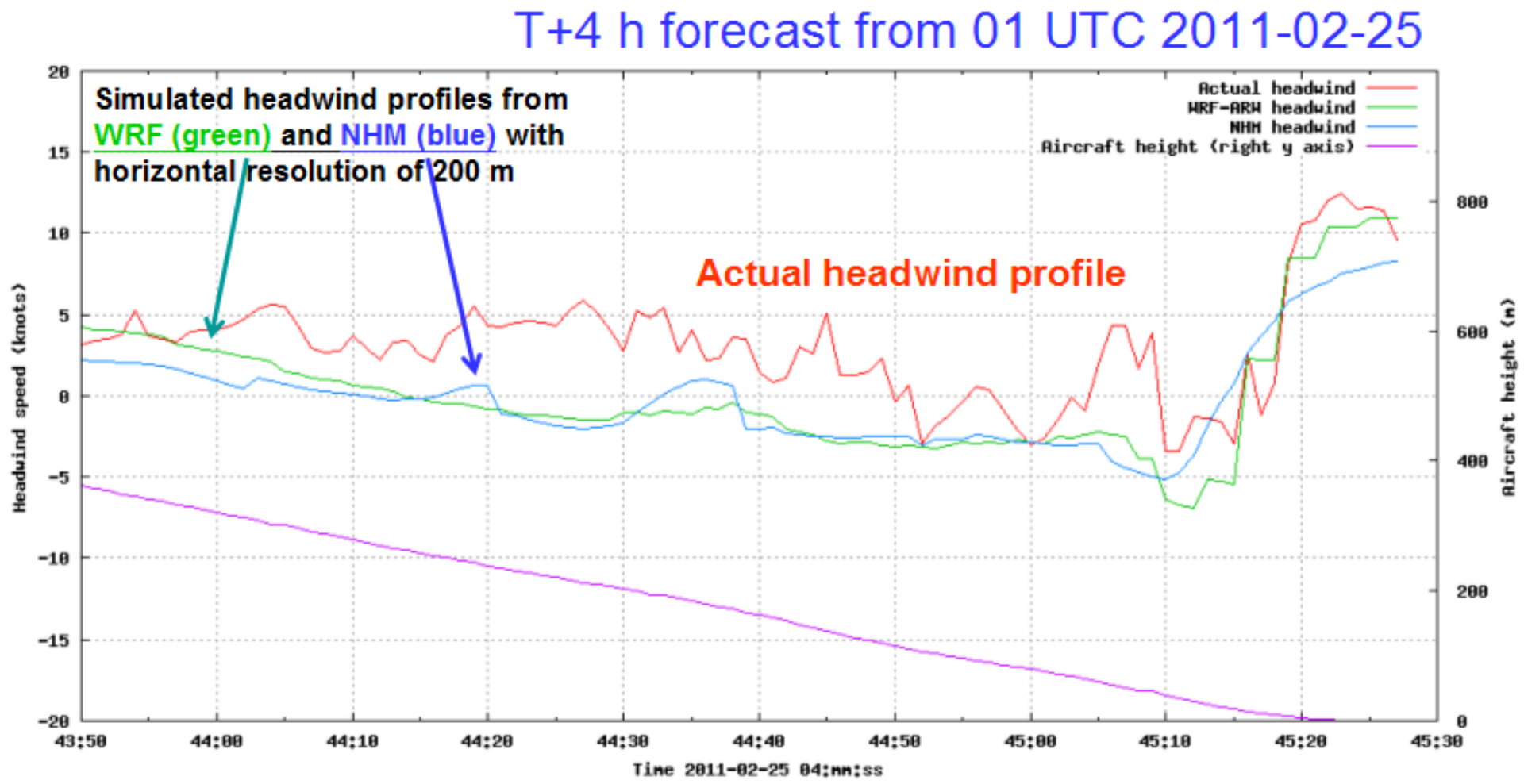


Windshear Events due to Sea Breeze

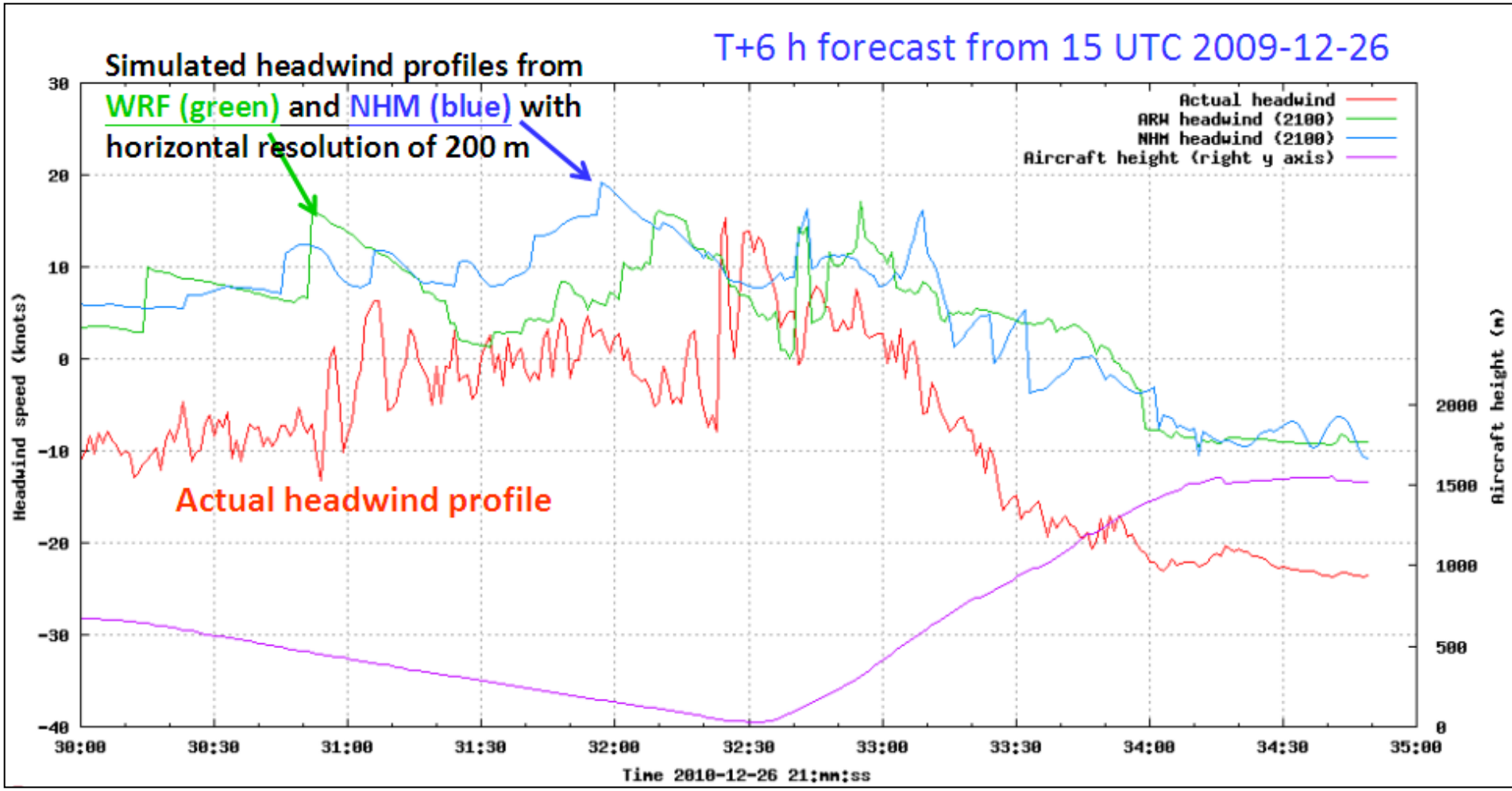


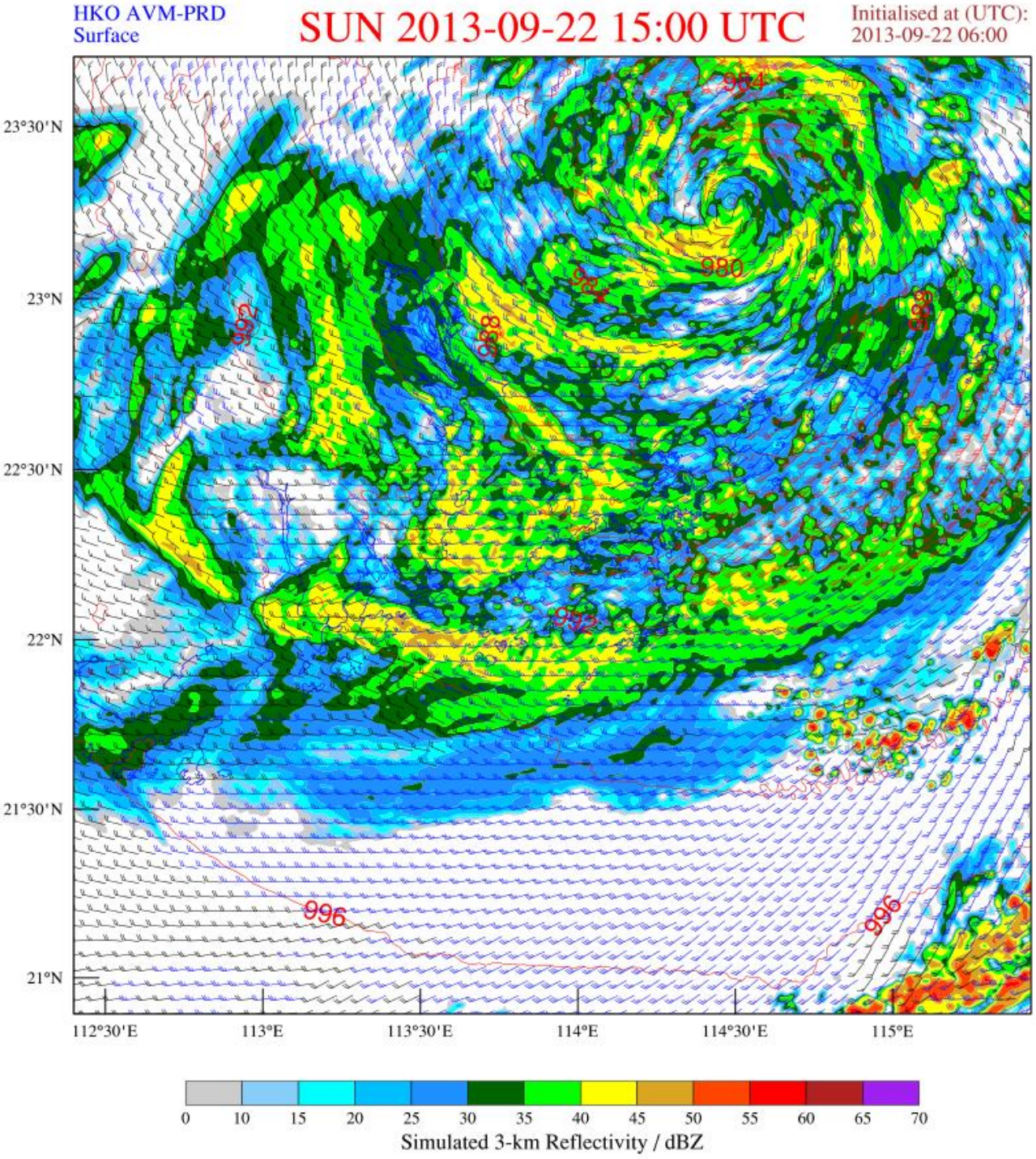


Headwind profile simulator (HKA-AVM) - Windshear due to sea-breeze



Headwind profile simulator (HKA-AVM) - Terrain-induced windshear




HKO AVM-PRD
Surface
SUN 2013-09-22 15:00 UTC
Initialised at (UTC):
2013-09-22 06:00
23°30'N
23°N
22°30'N
22°N
21°30'N
21°N
112°30'E
113°E
113°30'E
114°E
114°30'E
115°E
964
980
984
988
992
996
996
0
10
15
20
25
30
35
40
45
50
55
60
65
70
Simulated 3-km Reflectivity / dBZ

Looking Ahead – HKO-AVM

- Development of data assimilation system
  - Current initial & boundary conditions from RAPIDS-NHM (2 km)
  - "Dynamical Downscaling" in theory
  - Requires separate DA (based on WRF-VAR) for leveraging high-resolution observations in the vicinity HKIA
- Development of aviation-specific product suite
  - Low-level windshear and turbulence
  - Guidance for sea breeze onset / retreat timing, depth, etc
  - Chance of sig. convection at key locations around HKIA
- Development of near real-time verification system

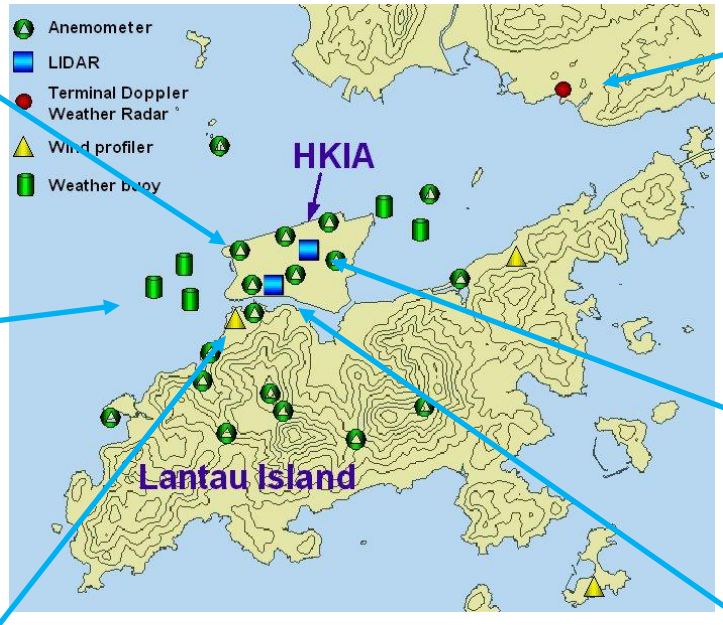
香港天文台
HONG KONG OBSERVATORY

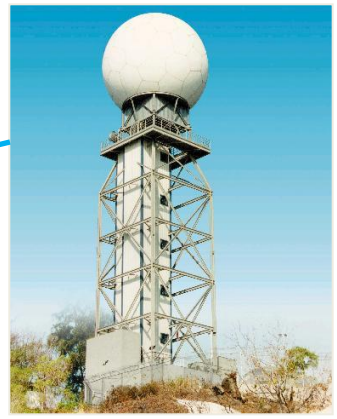
Observation Network around HKIA

Anemometer

Weather buoy

Wind profiler





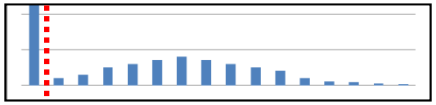
TDWR

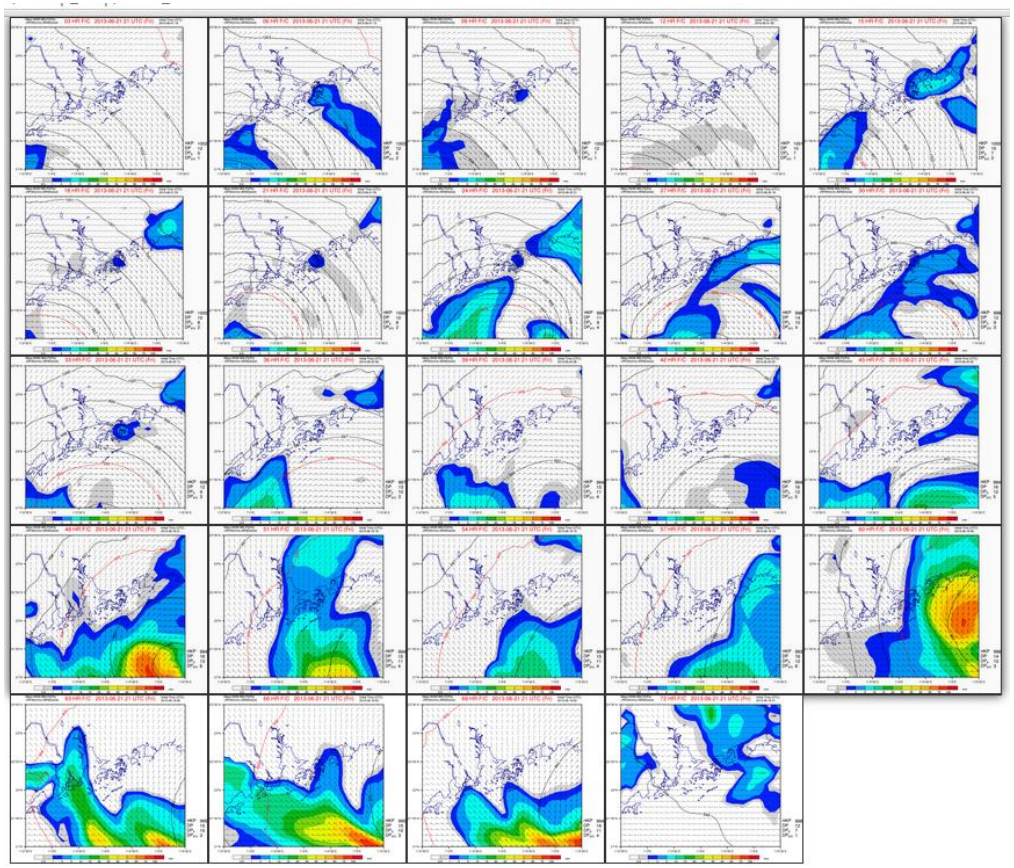
2nd LIDAR

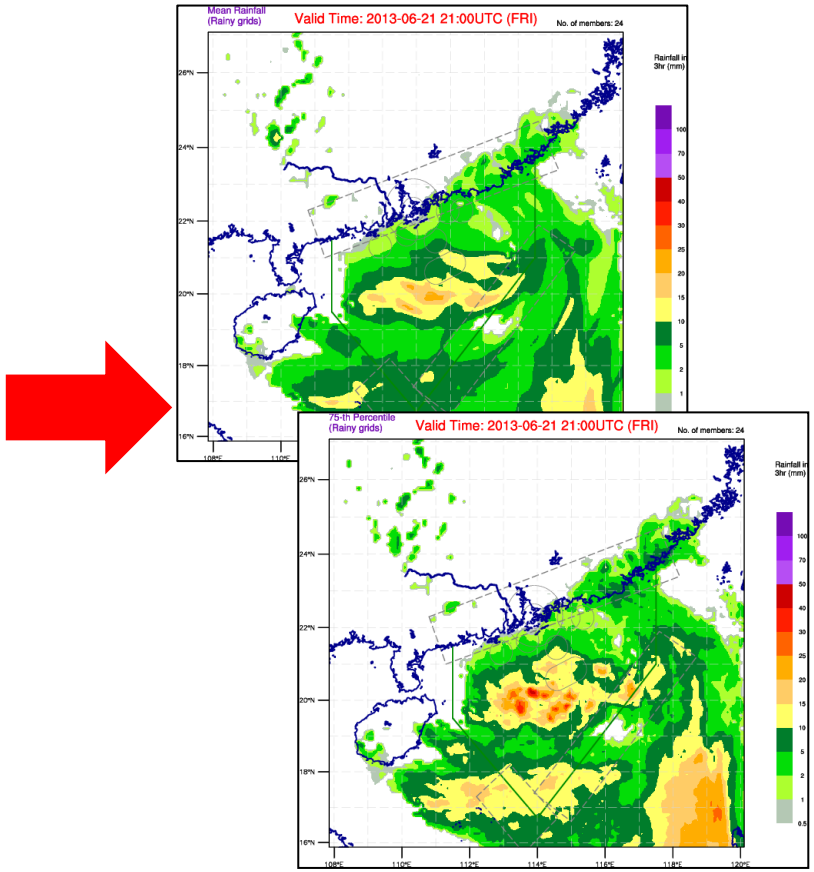
1st LIDAR

Meso-NHM QPF Ensemble

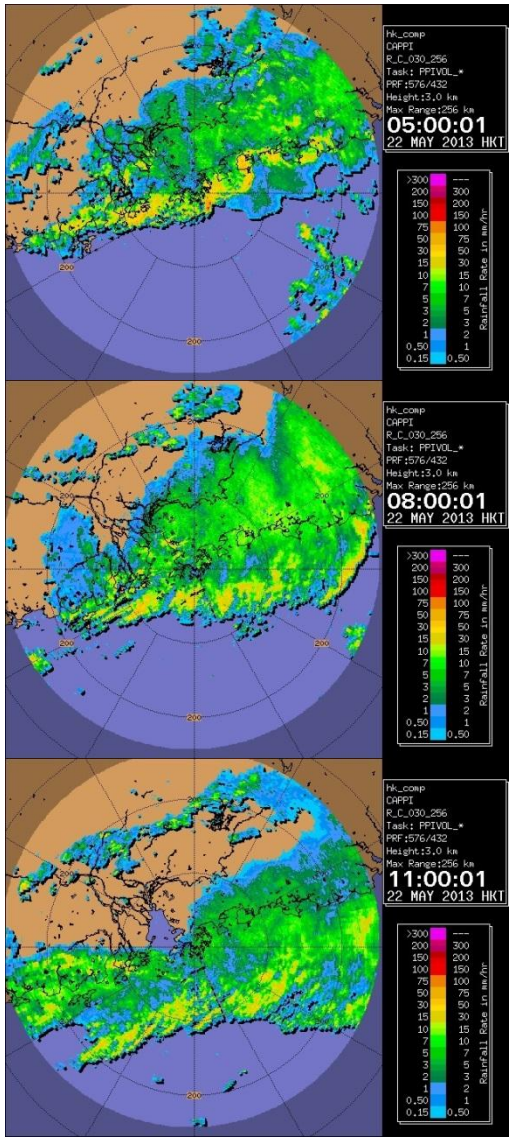
- Apply time-lagged ensemble approach to consecutive Meso/RAPIDS-NHM runs to generate QPF guidance
- 2 “flavours” – *all grid points* or *rainy grid only*

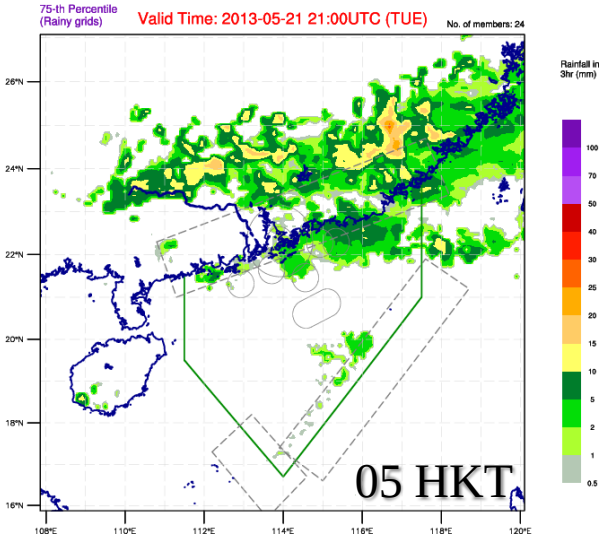


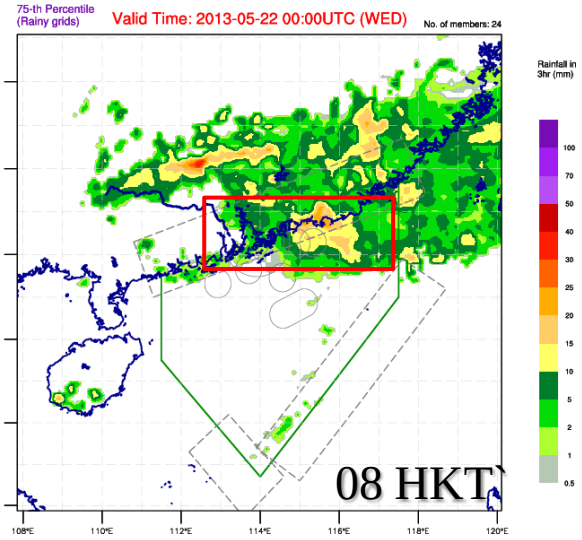


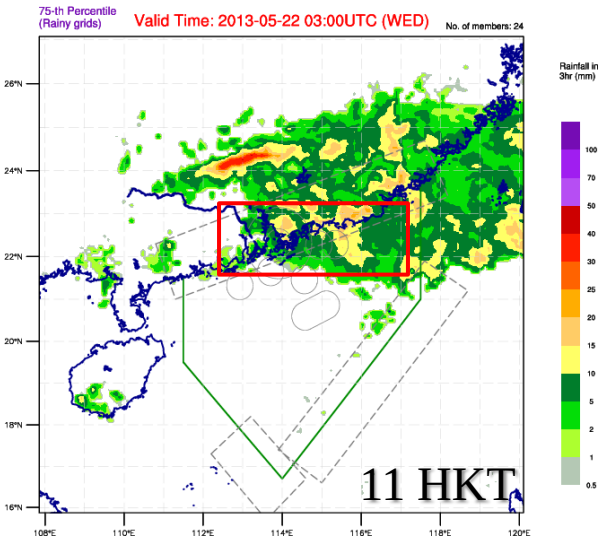


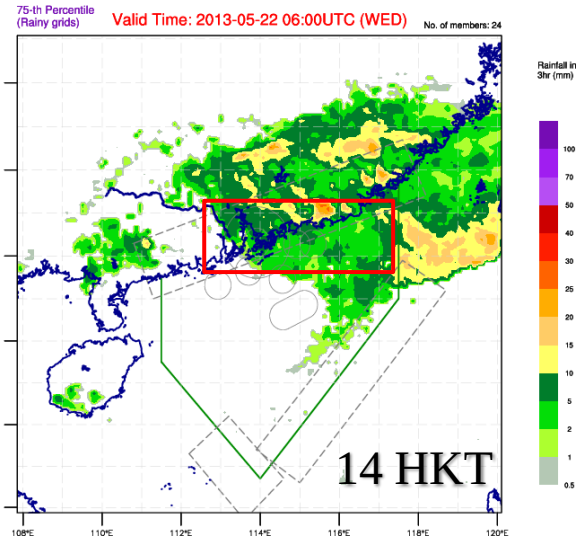
Rainstorm on 2013-05-22





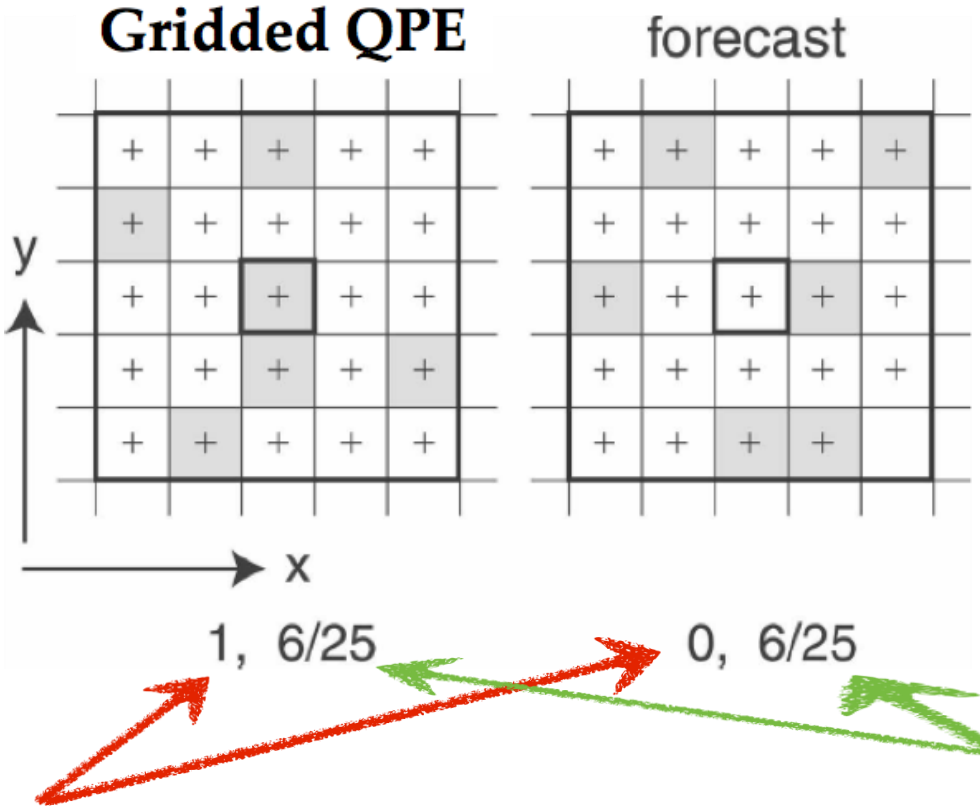






Verification of Spatial QPF Products

- Fractional Skill Score (FSS)
  - Incorporates spatial uncertainty information in model forecasts



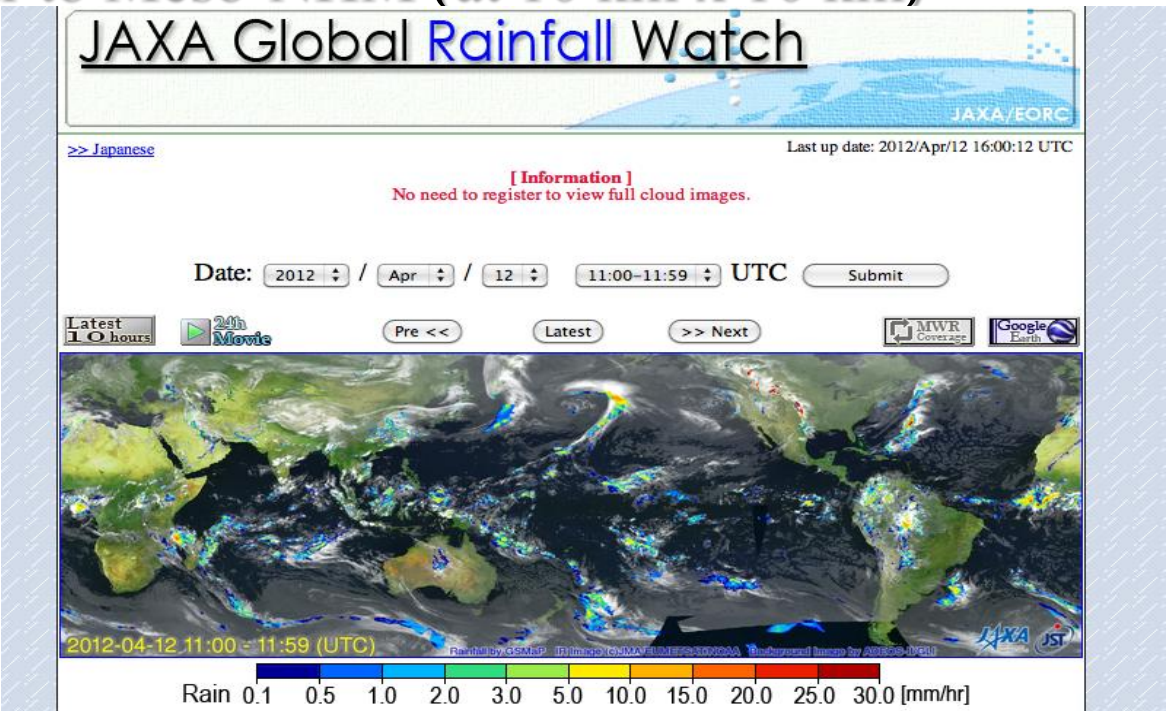
$$FSS = 1 - \frac{FBS}{\frac{1}{N}\left[\sum_N P_{fcst}^2 + \sum_N P_{obs}^2\right]}$$

$$FBS = \frac{1}{N}\sum_N \left(P_{fcst} - P_{obs}\right)^2$$

Grid-by-grid Comparison FSS – “good correspondence at +/- 2 grids”

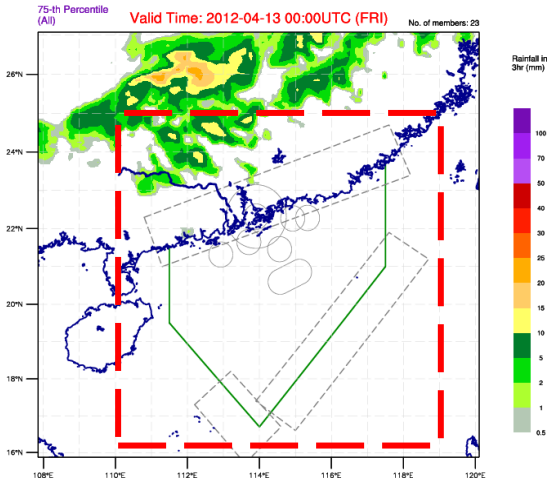
Verification of Spatial QPF Products

- JAXA Global Rainfall Watch Data (GSMaP)
- Near-real-time hourly rainfall rate based on MW-IR algorithm
  - Incorporating TRMM TMI, Aqua AMSR-E, DMSP SSM/I and SSMIS, NOAA-19 AMSU, MetOp-A AMSU and GEO IR data
- Data available at 0.1-deg resolution
  - Similar to Meso-NHM (at 10 km x 10 km)

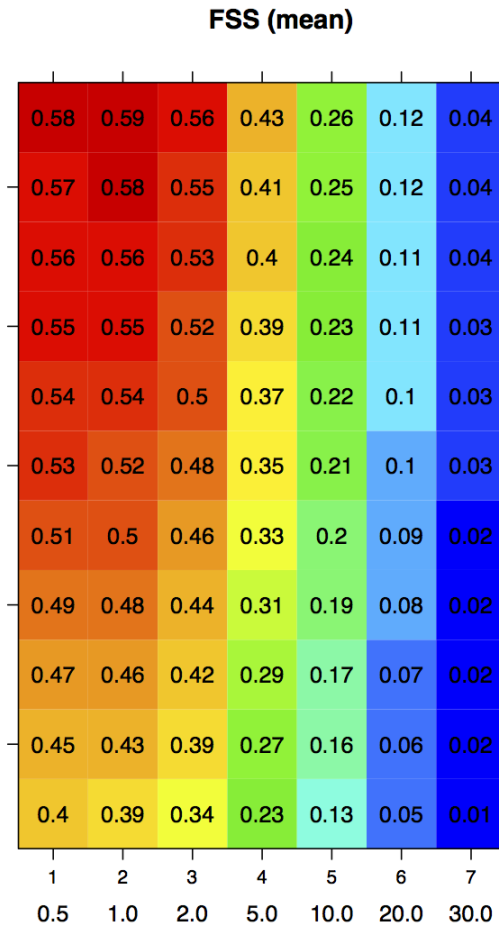


Verification of Spatial QPF Products

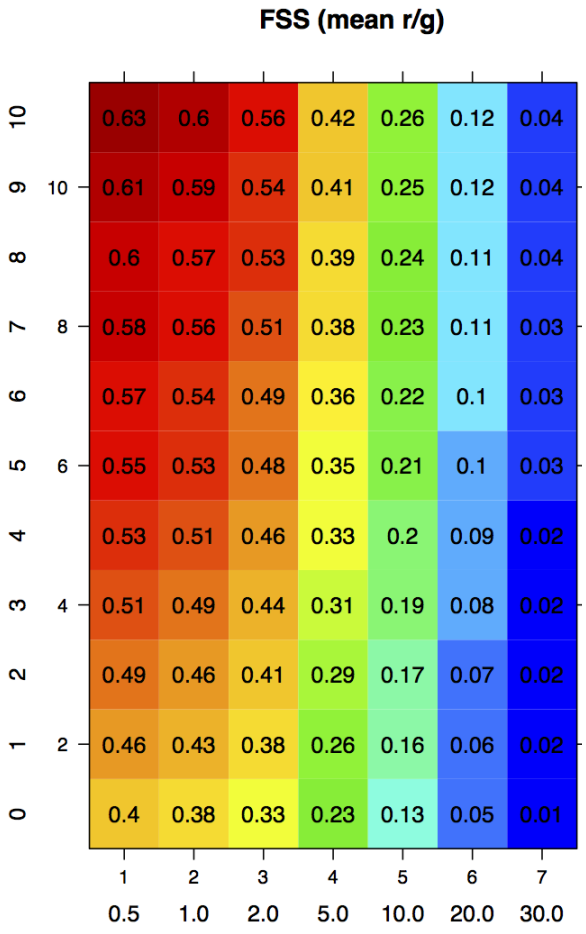
- Data period: 1 April - 30 Nov 2012
- Meso-NHM QPF ensemble (3-hr rainfall)
  - 6 choices:
    - ensemble mean (all and rain-grid)
    - 75 percentile (all and rain-grid)
    - median
    - max
- "Ground Truth": JAXA GSMaP
- Metric: FSS



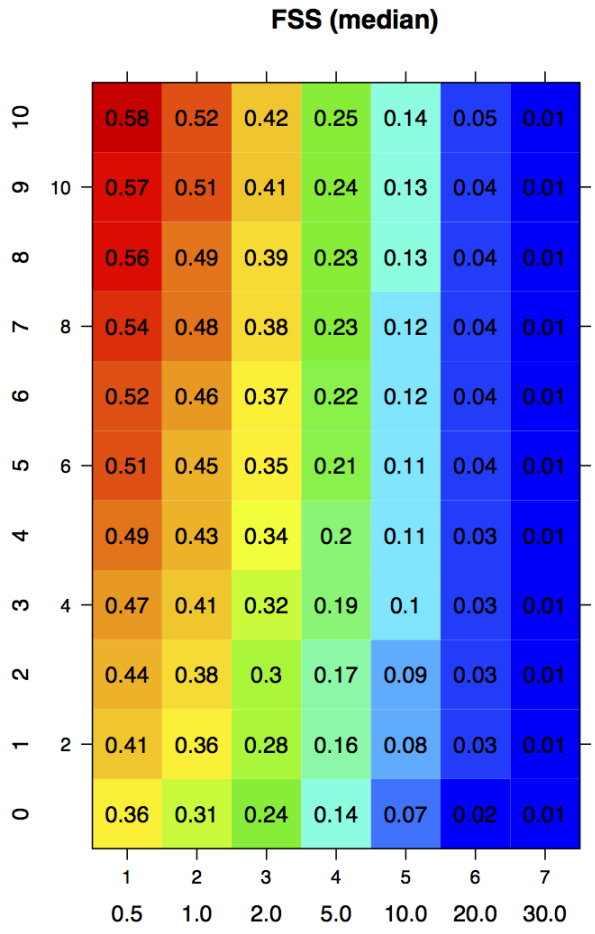
Sample FSS Scores for Meso-NHM



Mean

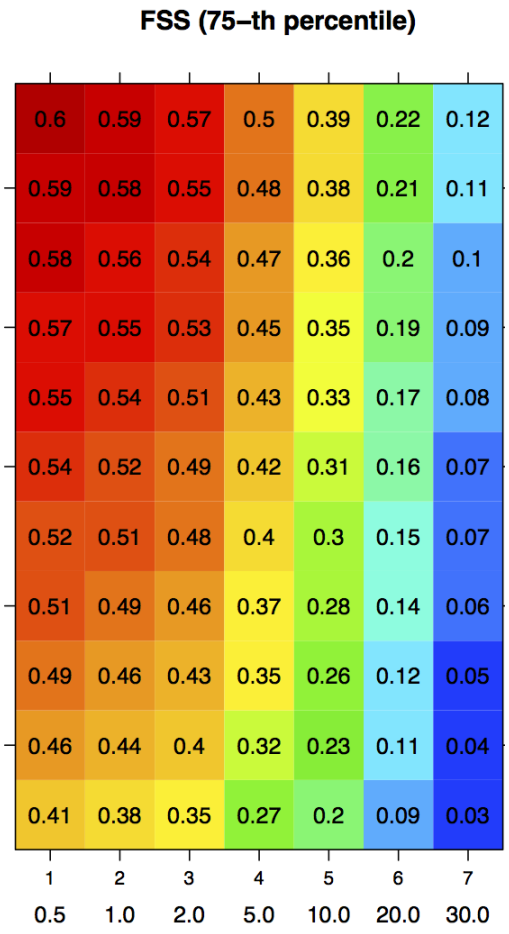


Mean (rain-grid)

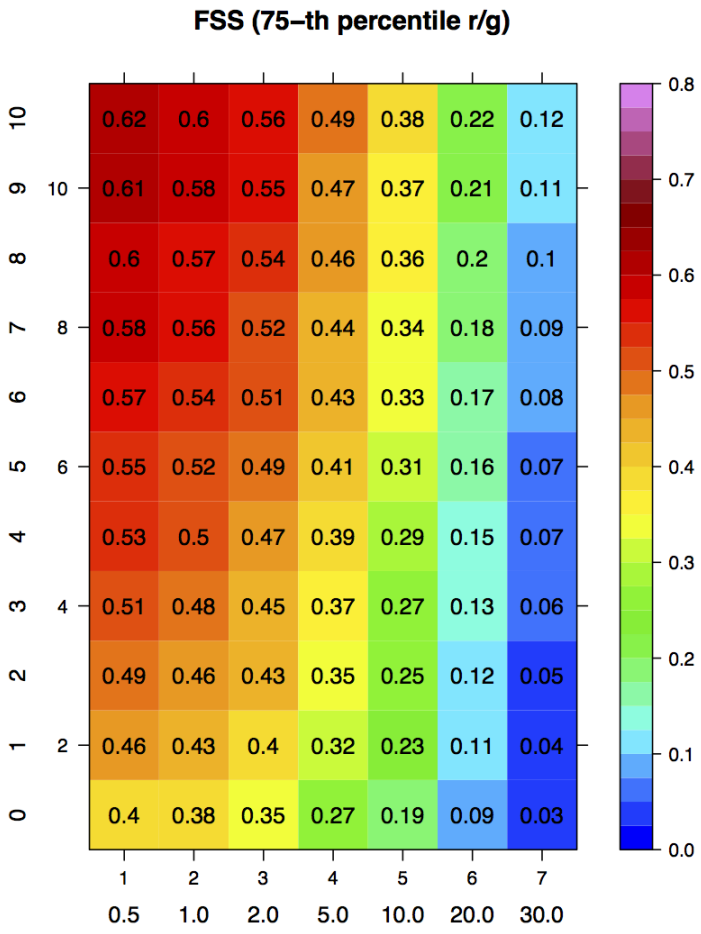


Median

Sample FSS Scores for Meso-NHM



75th Percentile

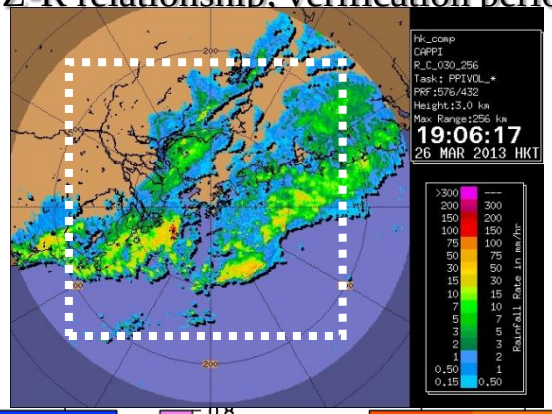


75th Percentile (rain-grid)

Maximum

RAPIDS-NHM

Verification area confined to within TMS 256 km range;
radar based QPE using static Z-R relationship; verification period: Apr - Nov 2012



0 to +/- 40 km

FSS (75–th percentile)

	0.5	1.0	2.0	5.0	10.0	20.0	30.0
20	0.51	0.48	0.43	0.31	0.14	0.05	0.03
19	0.51	0.47	0.42	0.31	0.15	0.05	0.03
18	0.5	0.47	0.42	0.3	0.16	0.06	0.03
17	0.5	0.46	0.41	0.3	0.16	0.06	0.03
16	0.49	0.45	0.41	0.3	0.16	0.06	0.02
15	0.48	0.45	0.4	0.29	0.16	0.06	0.02
14	0.47	0.44	0.39	0.28	0.16	0.05	0.02
13	0.47	0.43	0.38	0.27	0.15	0.05	0.02
12	0.46	0.42	0.37	0.26	0.15	0.05	0.02
11	0.45	0.42	0.36	0.26	0.14	0.04	0.02
10	0.44	0.41	0.35	0.25	0.13	0.04	0.02
9	0.44	0.4	0.34	0.24	0.13	0.04	0.01
8	0.43	0.39	0.34	0.23	0.12	0.03	0.01
7	0.42	0.38	0.32	0.22	0.11	0.03	0.01
6	0.41	0.37	0.31	0.21	0.1	0.03	0.01
5	0.4	0.36	0.3	0.19	0.09	0.03	0.01
4	0.39	0.35	0.29	0.18	0.09	0.02	0.01
3	0.37	0.33	0.27	0.17	0.08	0.02	0.01
2	0.36	0.31	0.26	0.15	0.07	0.02	0.01
1	0.33	0.29	0.24	0.14	0.06	0.01	0
0	0.29	0.25	0.19	0.1	0.04	0.01	0

FSS (75–th percentile r/g)

	0.5	1.0	2.0	5.0	10.0	20.0	30.0
20	0.51	0.49	0.43	0.3	0.14	0.05	0.03
19	0.5	0.48	0.43	0.3	0.15	0.05	0.03
18	0.5	0.48	0.42	0.3	0.15	0.06	0.03
17	0.49	0.47	0.42	0.3	0.16	0.06	0.02
16	0.49	0.46	0.41	0.29	0.16	0.06	0.02
15	0.48	0.45	0.4	0.29	0.16	0.06	0.02
14	0.47	0.45	0.39	0.28	0.16	0.05	0.02
13	0.46	0.44	0.38	0.27	0.15	0.05	0.02
12	0.45	0.43	0.38	0.26	0.14	0.05	0.02
11	0.44	0.42	0.37	0.25	0.14	0.04	0.02
10	0.43	0.41	0.36	0.24	0.13	0.04	0.02
9	0.42	0.4	0.35	0.23	0.12	0.04	0.01
8	0.41	0.39	0.34	0.22	0.12	0.03	0.01
7	0.4	0.38	0.32	0.21	0.11	0.03	0.01
6	0.39	0.36	0.31	0.2	0.1	0.03	0.01
5	0.37	0.35	0.3	0.19	0.09	0.03	0.01
4	0.36	0.34	0.29	0.18	0.09	0.02	0.01
3	0.34	0.32	0.27	0.17	0.08	0.02	0.01
2	0.32	0.3	0.25	0.15	0.07	0.02	0.01
1	0.3	0.28	0.23	0.14	0.06	0.01	0
0	0.25	0.23	0.19	0.1	0.04	0.01	0

raction Skill Score as function of lead time (Meso-NHM)