

Use and Interpretation of Deterministic NWP Models

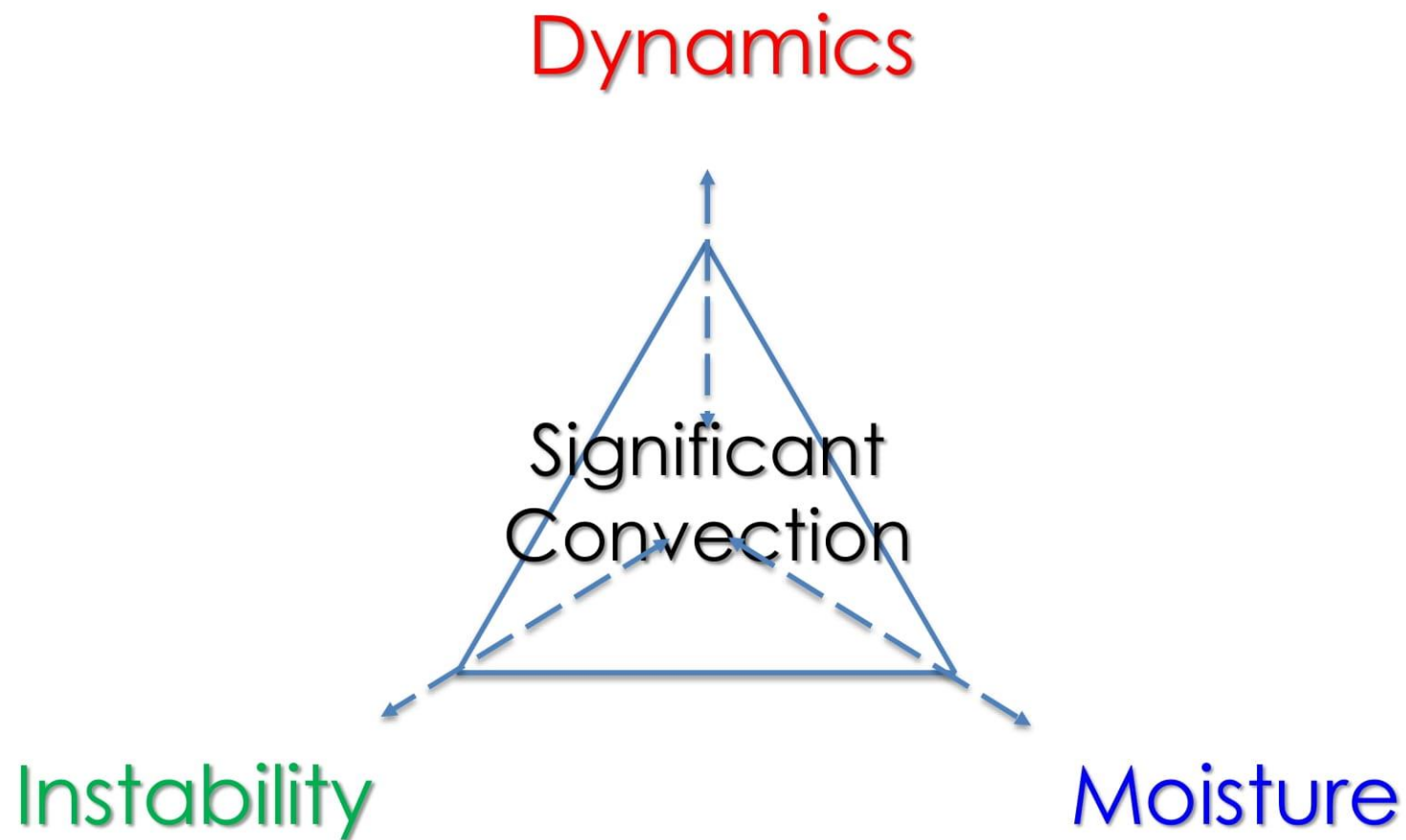
Wai-Kin Wong

Senior Scientific Officer, Forecast Development Division

VCP Online Workshop on Development of Products from NWP Models and
EPS for High-Impact Weather Forecasting

8-11 December 2020

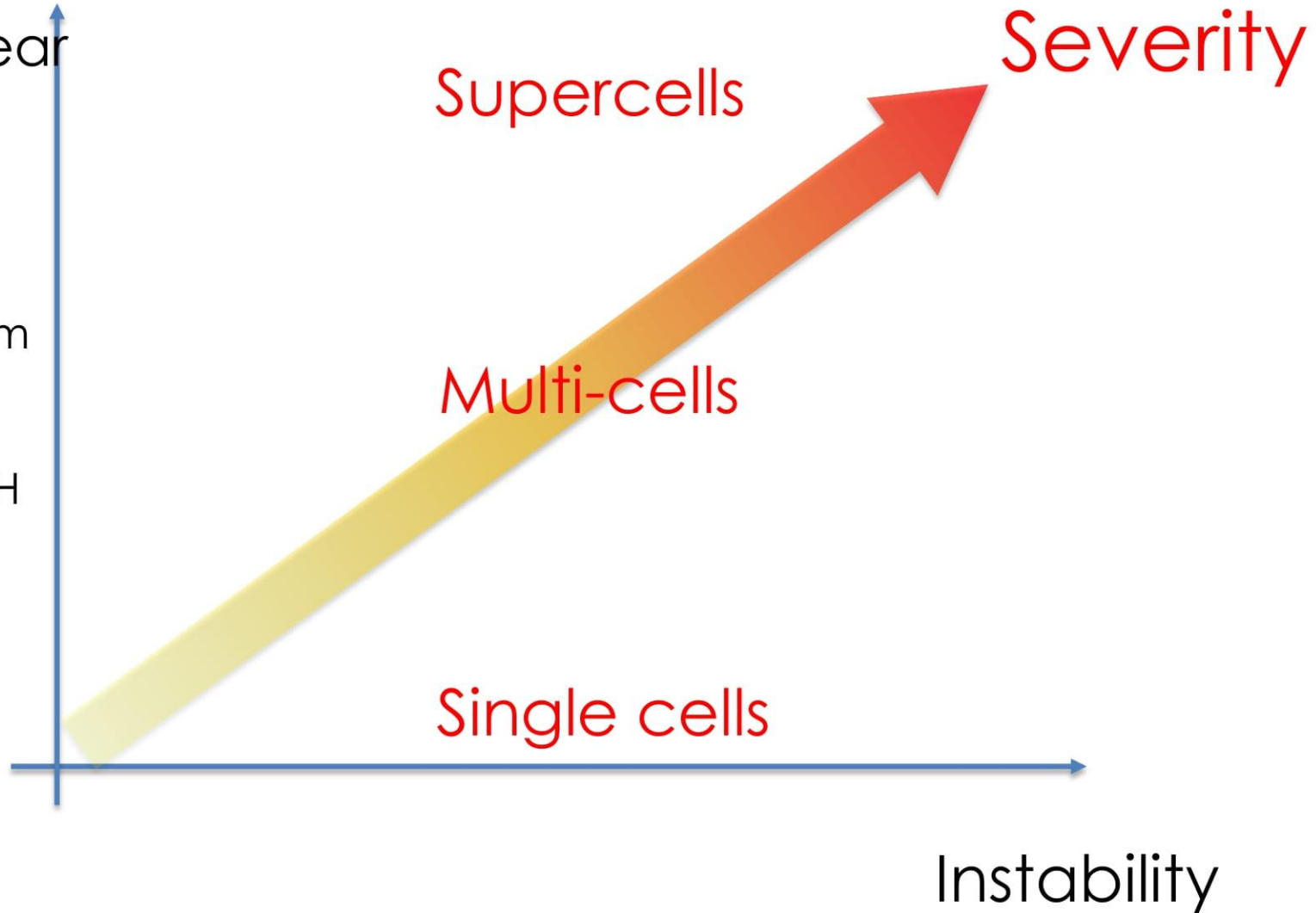
Perspectives of predicting high-impact convective weather processes



Convective Modes

Vertical
wind shear

Bulk shear vectors in 0-6 km
layer
Bulk Richardson shear
Storm-relative helicity SREH



Global distribution of mesoscale convective complexes from satellite observations

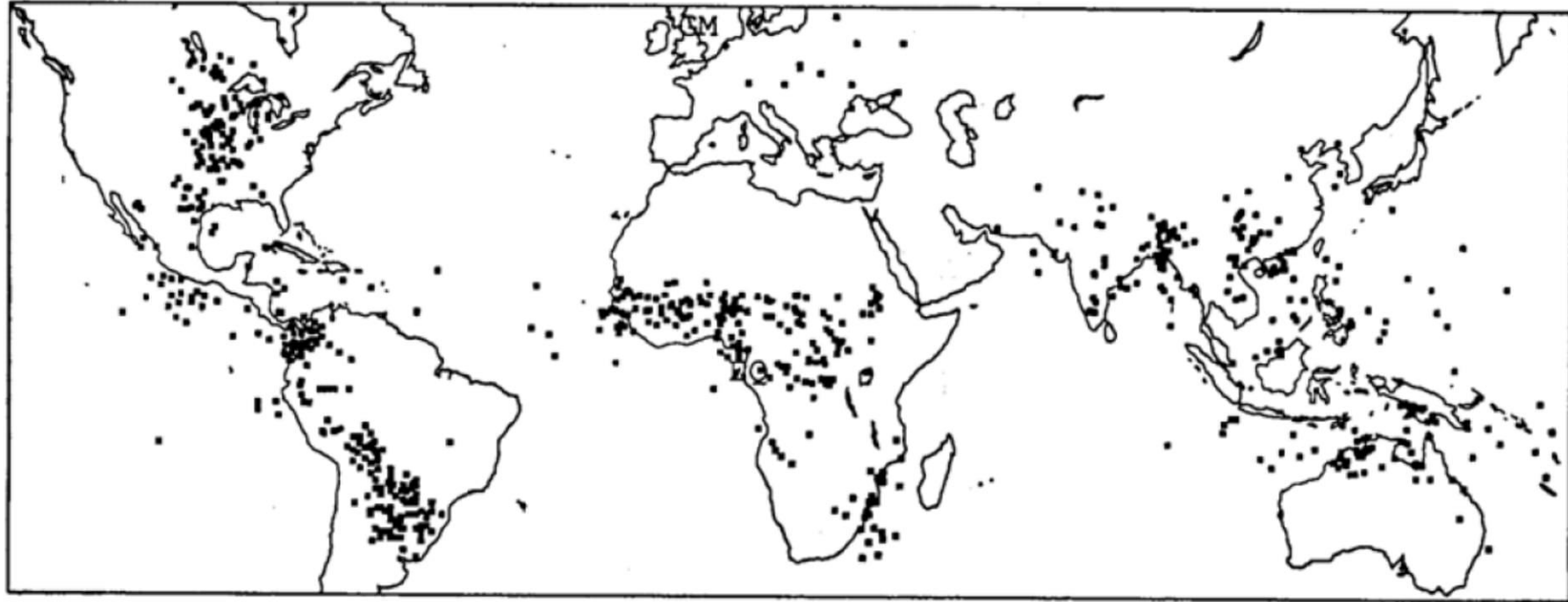
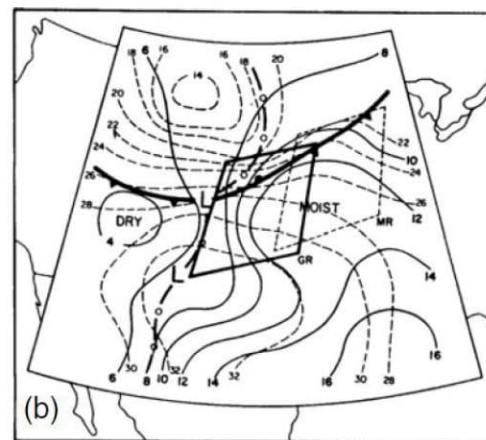
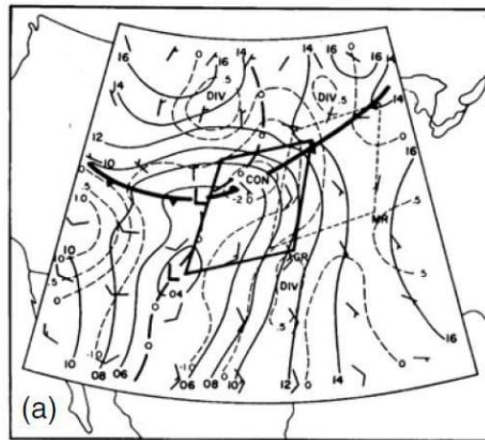


FIGURE 9.16 Locations of MCCs based on 1-3-yr regional samples of satellite imagery (from Laing and Fritsch, 1997). Locations are shown for the time of maximum extent of the cold-cloud shield. (From Fritsch and Forbes (2001))

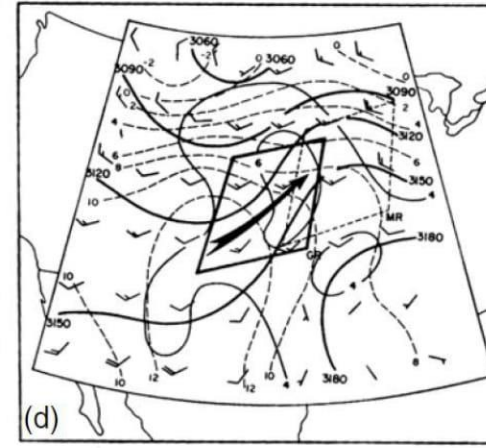
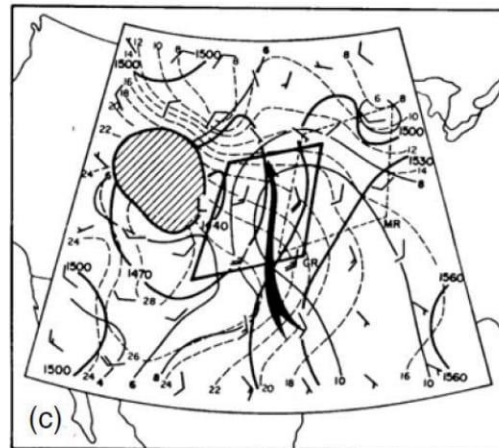
Synoptic features conducive to MCC development

Surface winds and isobars (solid) and divergence (dashed)



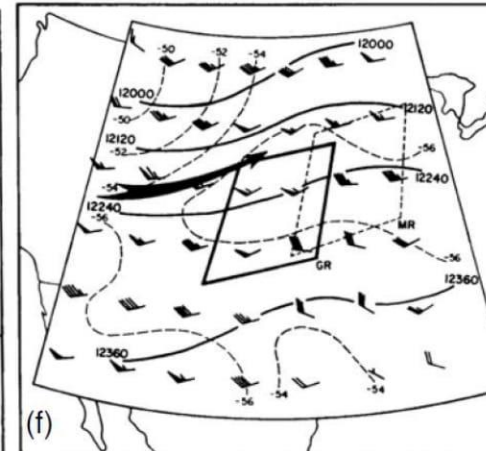
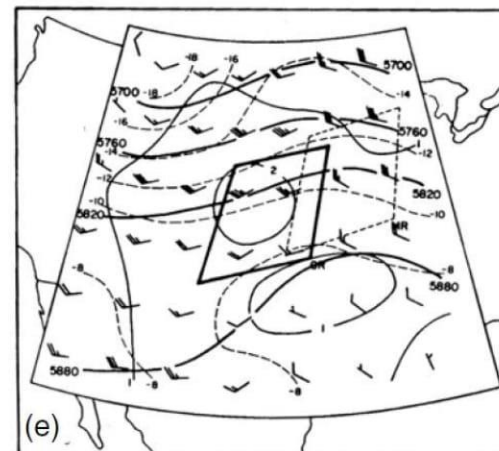
Surface isotherms (dotted) and mixing ratio (solid)

850 hPa height (solid), isotherm (dashed) and mixing ratio (thin solid lines)



700 hPa height (solid), isotherm (dashed) and mixing ratio (thin solid lines)

500 hPa height (solid), isotherm (dashed) and mixing ratio (thin solid lines)



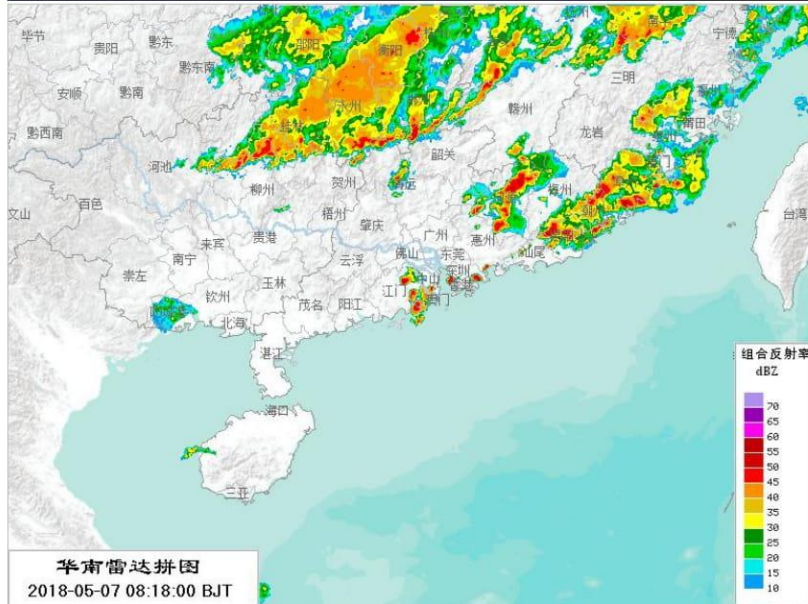
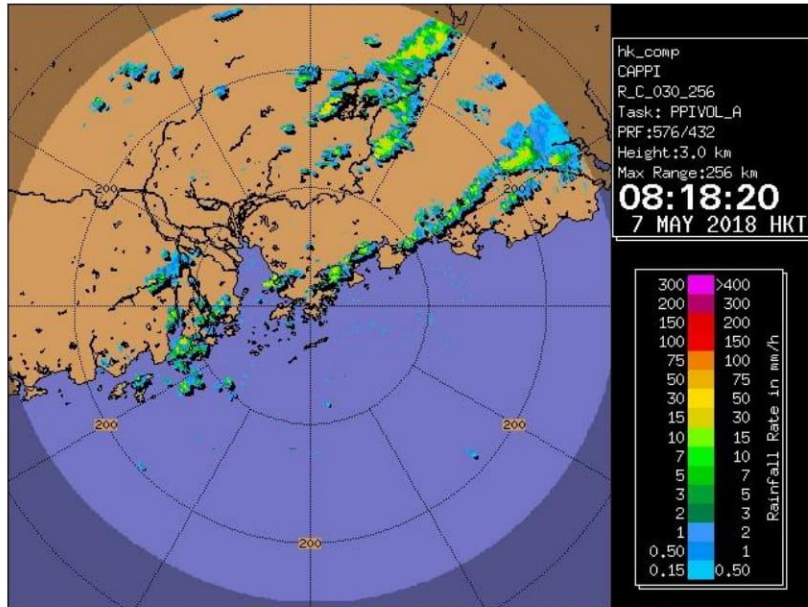
200 hPa height (solid), isotherm (dashed) and mixing ratio (thin solid lines)

Precursors of Mesoscale Convective Processes

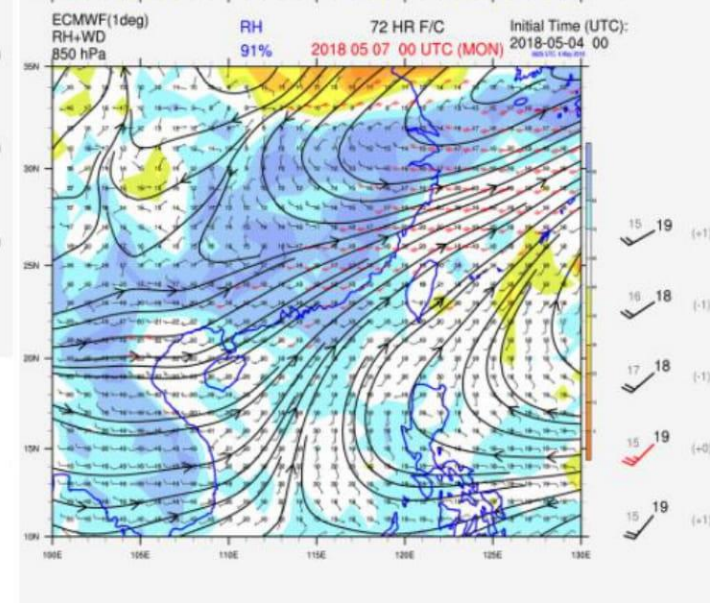
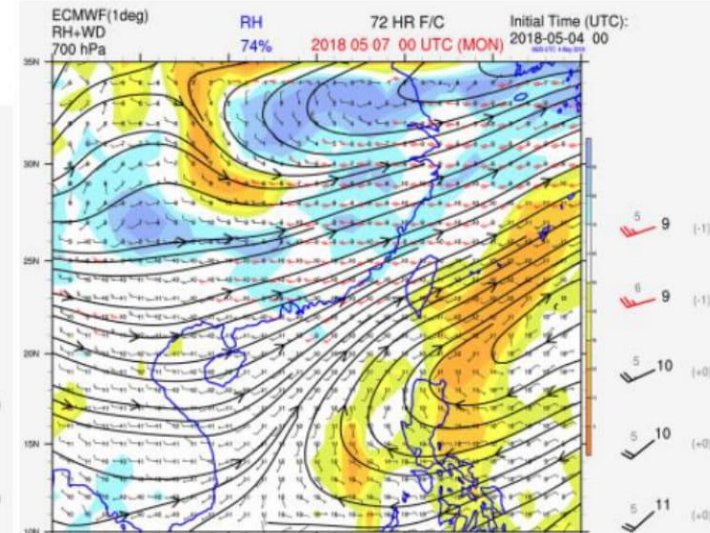
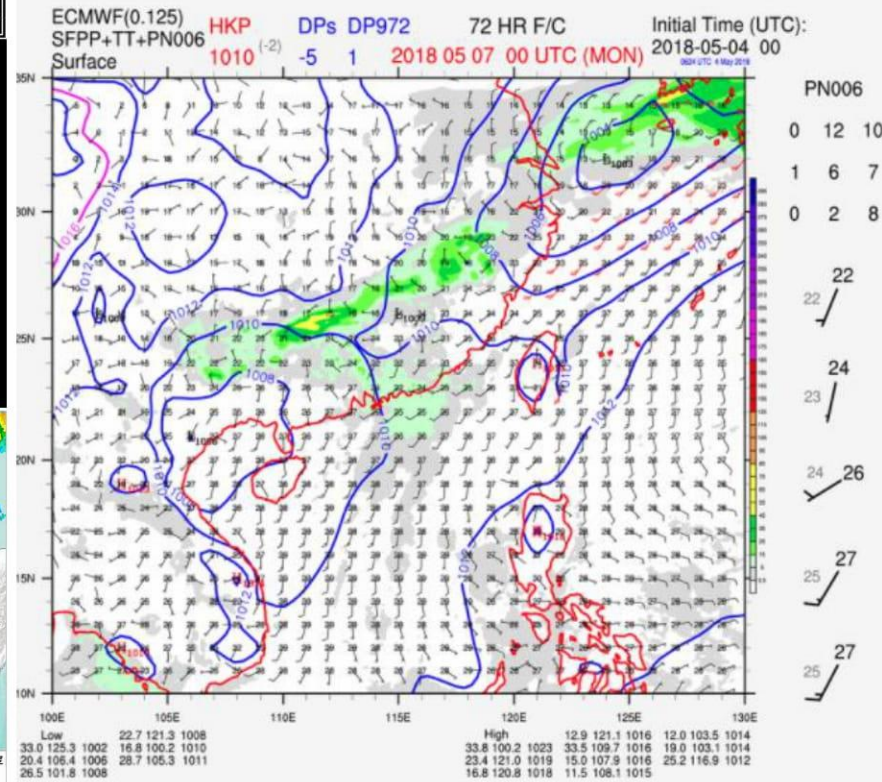
Local	Advective	Dynamical
Boundary layer processes <ul style="list-style-type: none"> ● Deepening the mixed layer ● Deepening the moist layer ● Convergence along dryline ● Nocturnal inversion, low-level jet formation 	Differential advection <ul style="list-style-type: none"> ● Creation of capping inversion ● Destabilization ● Formation of deep dry PBL 	Secondary circulations <ul style="list-style-type: none"> ● Geostrophic adjustment ● Jets
Terrain effects <ul style="list-style-type: none"> ● Creation of convergence zones ● Development of slope flows ● Modification of hodograph 	Convergence lines <ul style="list-style-type: none"> ● Fronts ● Drylines ● Land-sea breezes ● Mountain/valley breezes 	Gravity currents, waves <ul style="list-style-type: none"> ● Cold pool lifting ● Localized reduction of CIN ● Modification of vertical shear
Surface effects <ul style="list-style-type: none"> ● Evaporation, heating ● Discontinuous soil moisture/roughness 	Moisture advection <ul style="list-style-type: none"> ● Increase CAPE, lower LFC ● Local cumulus moistening 	Mesoscale instabilities <ul style="list-style-type: none"> ● Boundary layer processes ● Horizontal convective rolls ● Inertial oscillation

Strengths and weaknesses of NWP models

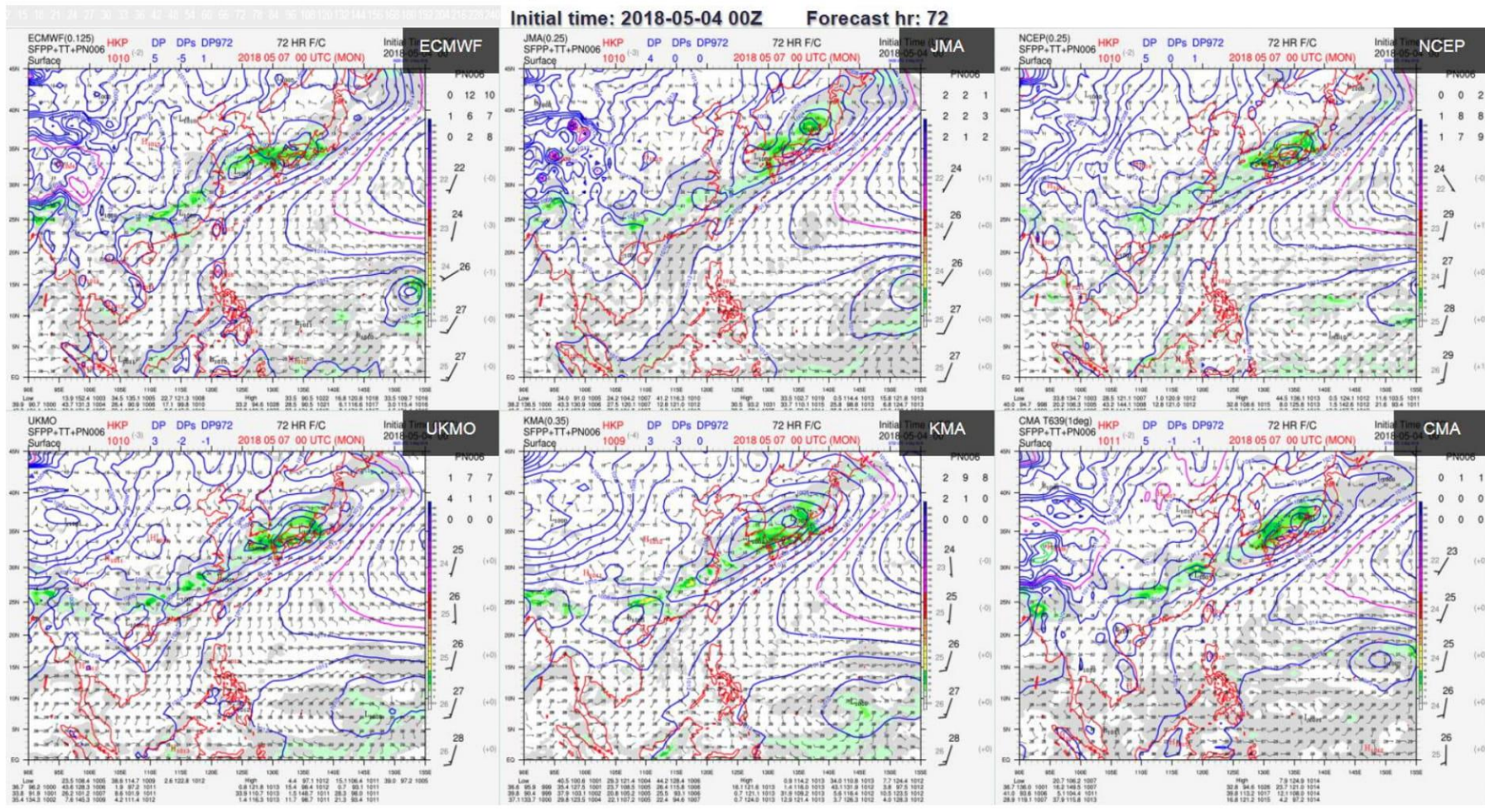
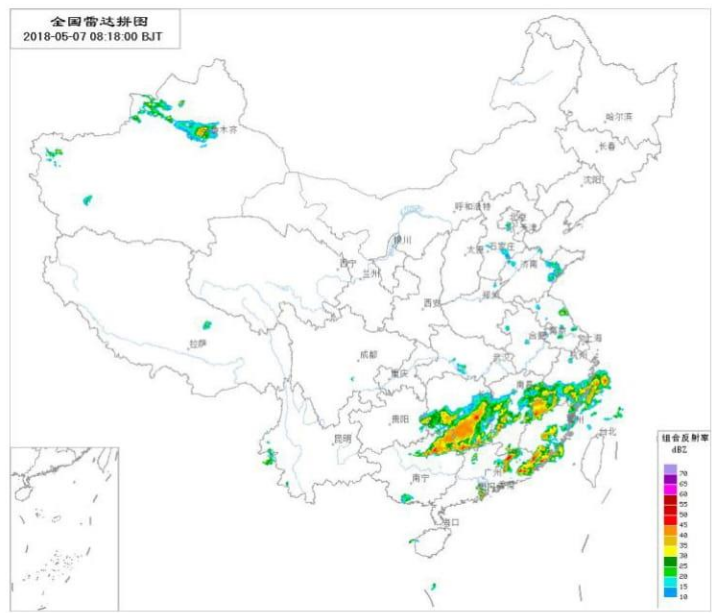
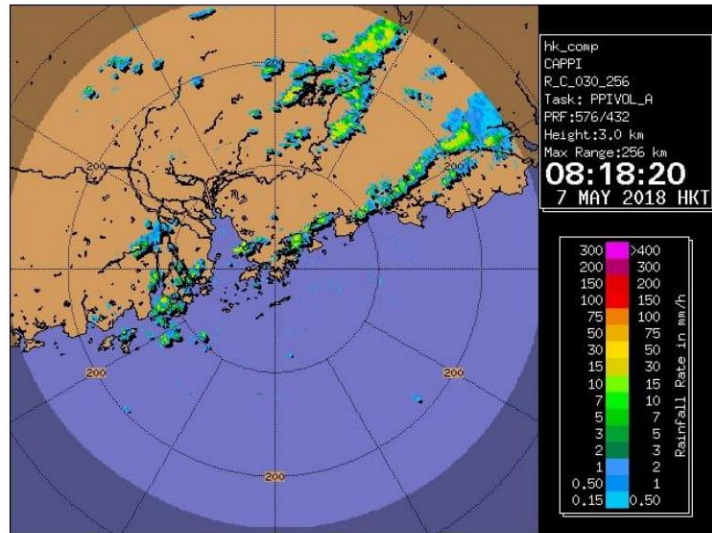
Dynamics and Moisture

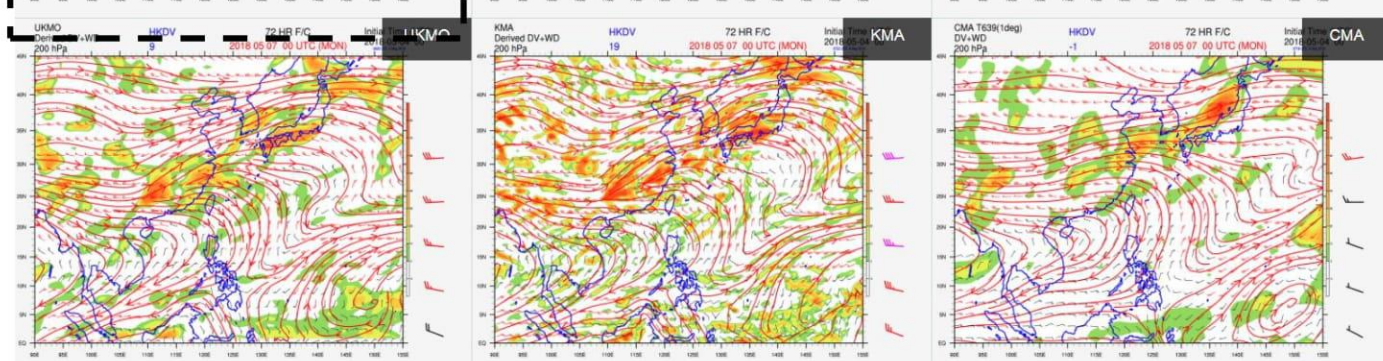
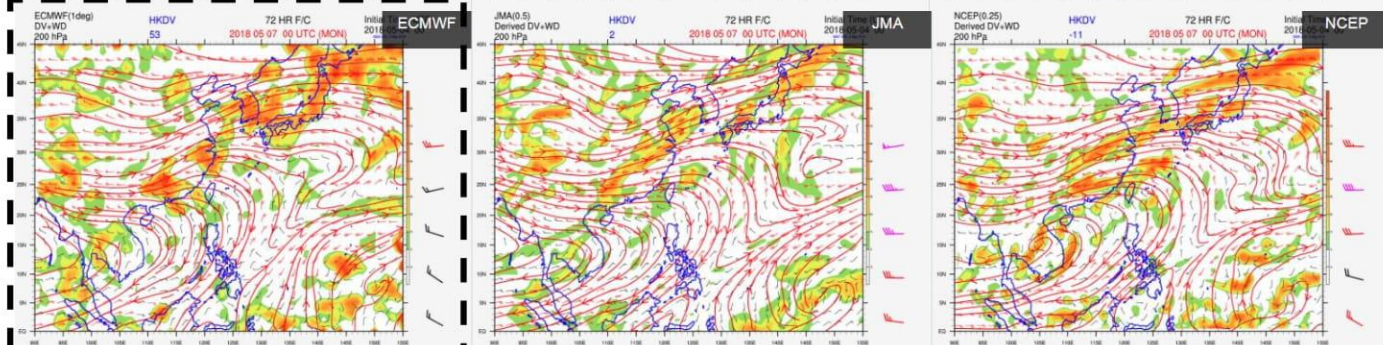
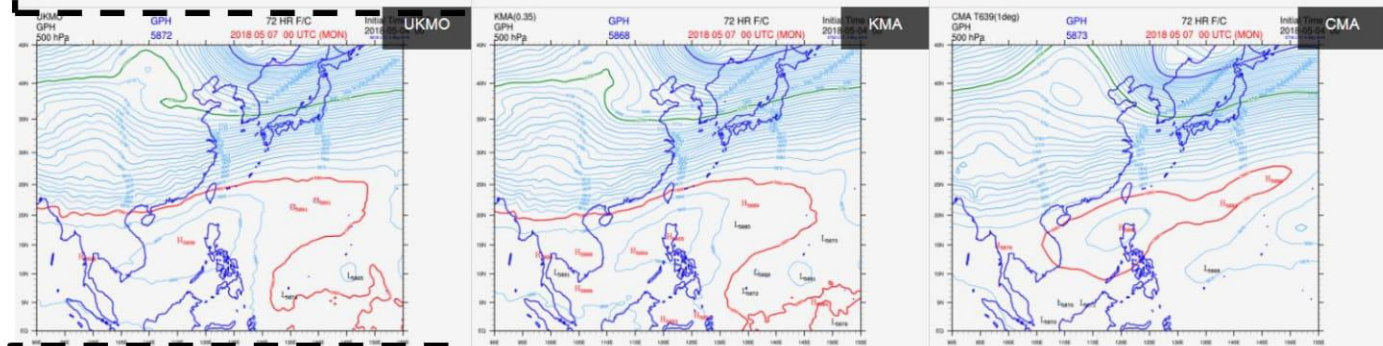
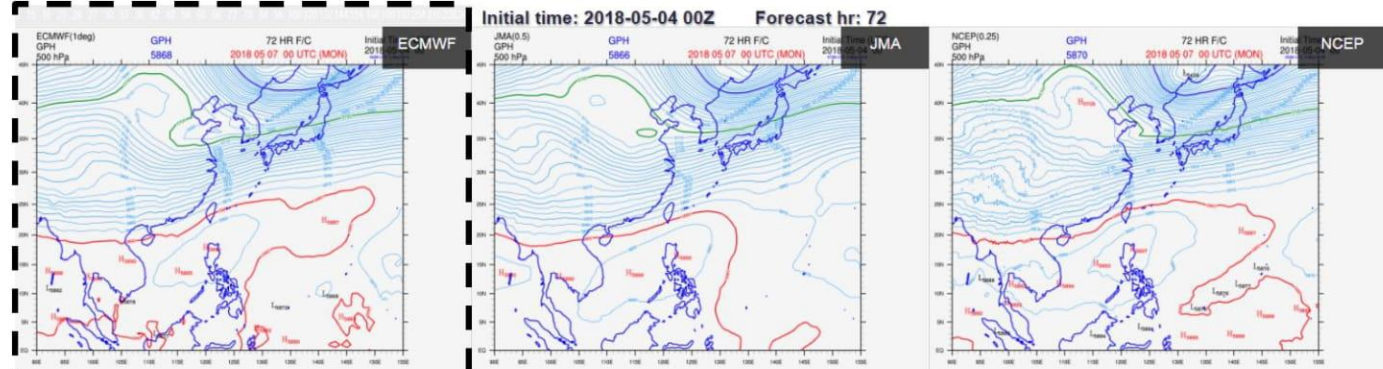
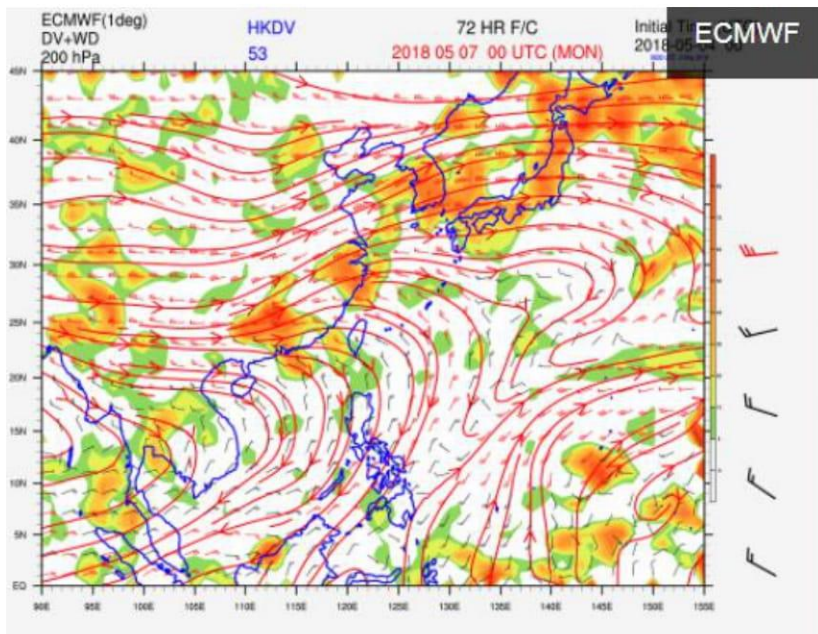
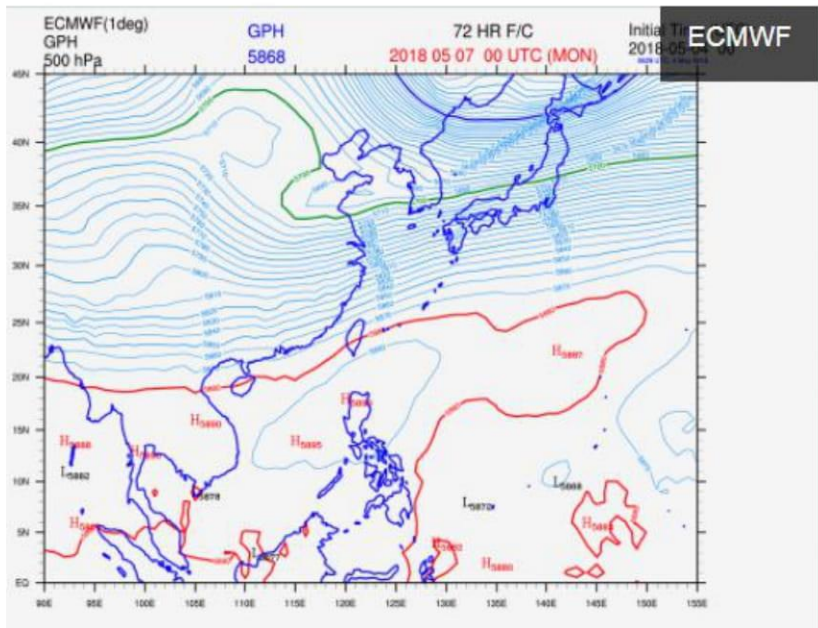


Initial time: 2018-05-04 00Z Forecast hr: 72

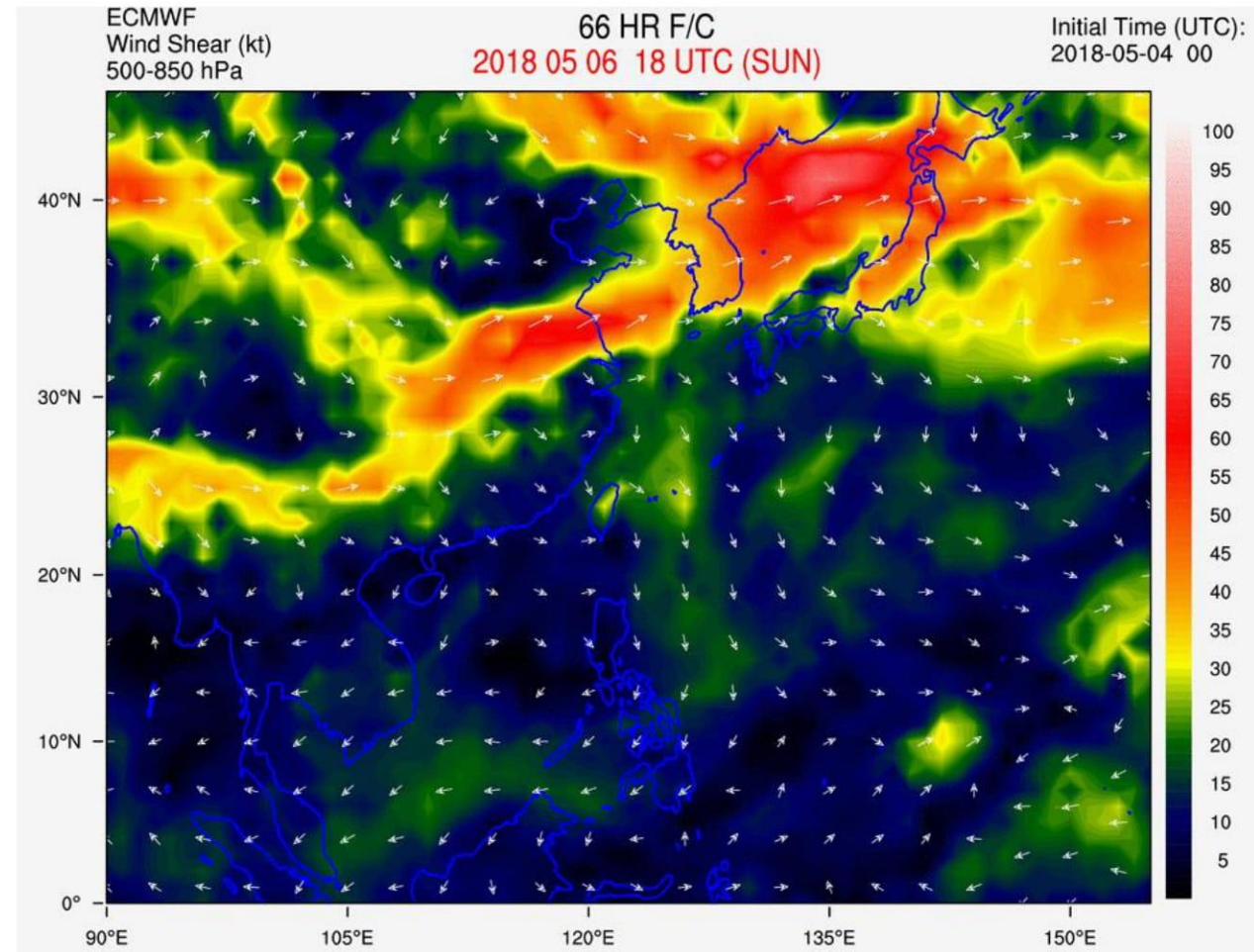
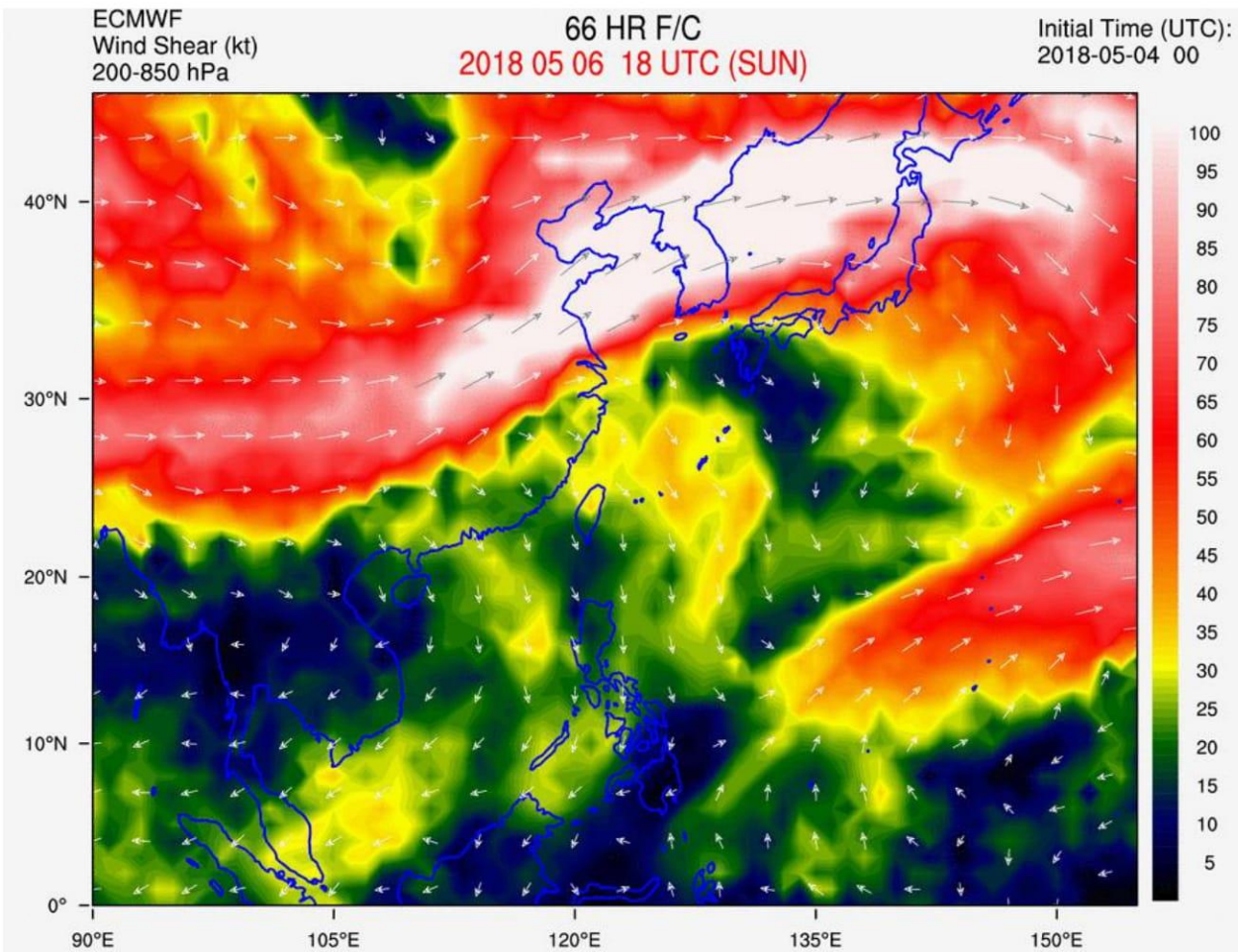


Multi-model comparisons



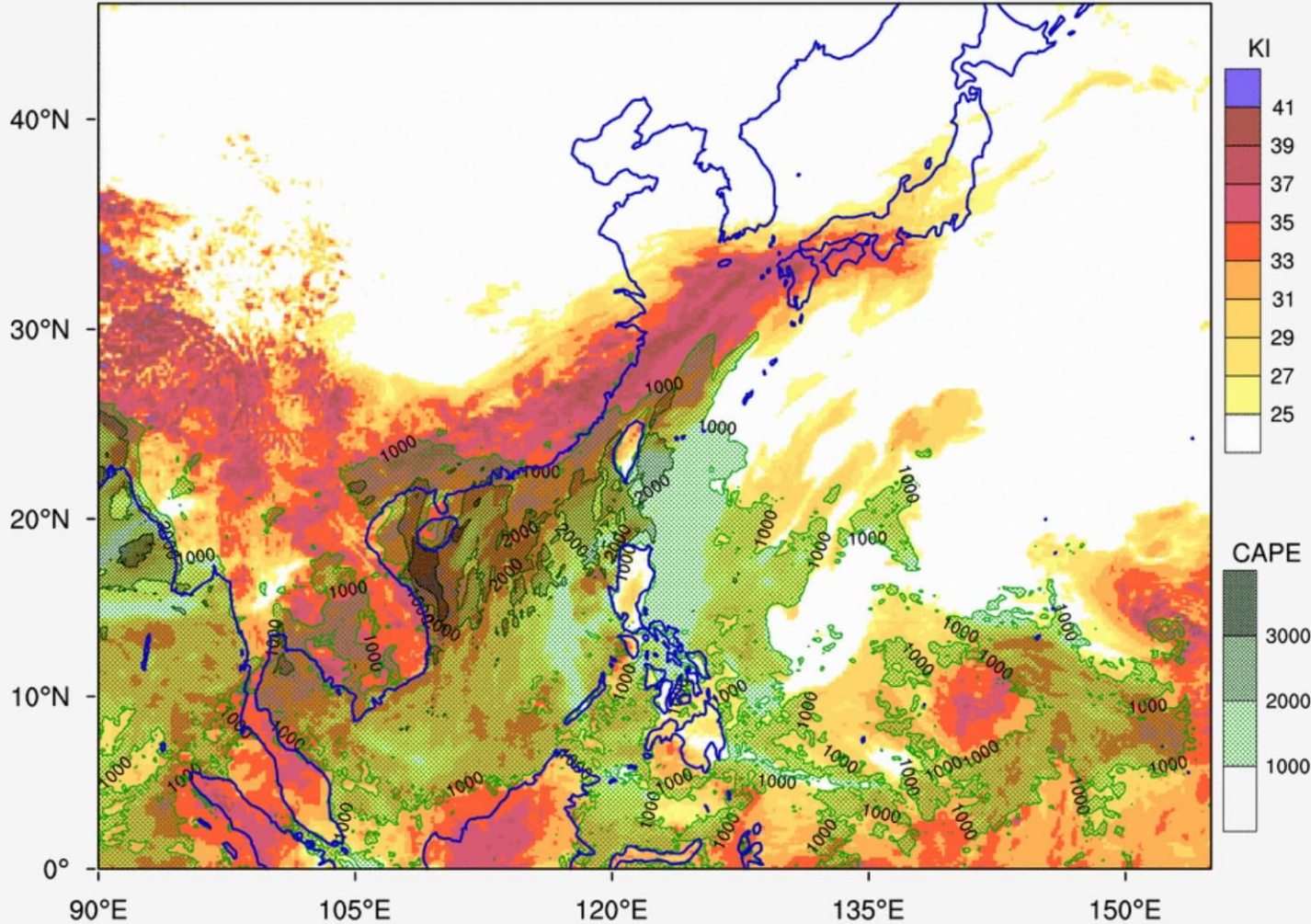


Vertical Wind Shear

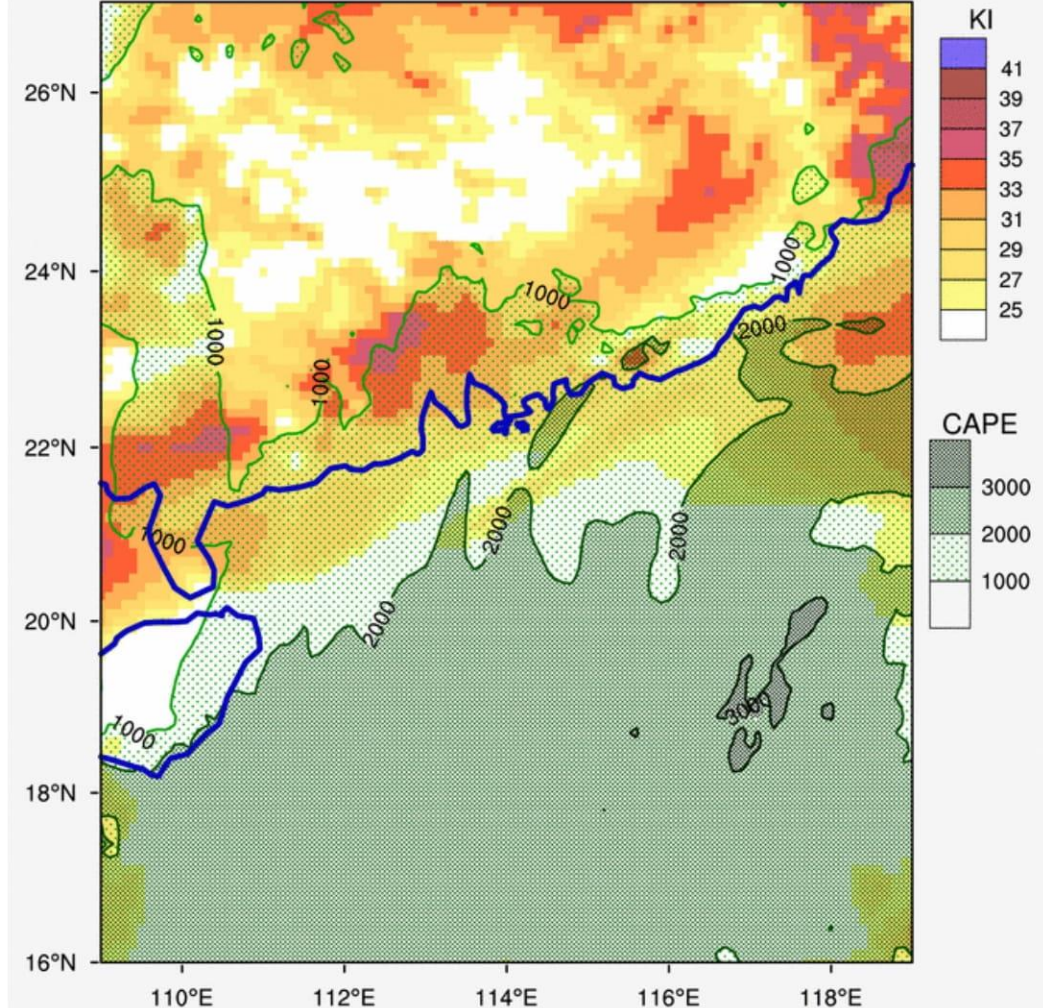


Instabilities

ECMWF
K-index (K) **KI 35**
CAPE (J/kg) **CAPE 957**
072 HR F/C
2018 05 07 00 UTC (MON)
Initial Time (UTC):
2018-05-04 00



ECMWF(0.1) **KI 29** **CAPE 1869**
K-index (K) **KI 29**
CAPE (J/kg) **CAPE 1869**
072 HR F/C
2020 05 07 00 UTC (THU)
Initial Time (UTC):
2020-05-04 00



Stability Indices

- K-index

- $KI = (T_{850} - T_{500}) + (T_{d850} - T_{dd700})$

Vertical totals high 850 hPa Td + small 700 hPa dew-point depression suggesting a deep layer of warm and moist air in the lower to middle troposphere

- Convective Available Potential Energy (CAPE)

$$CAPE = \int_{z_f}^{z_n} g \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) dz$$

z_n : level of neutral buoyancy
 z_f : LFC

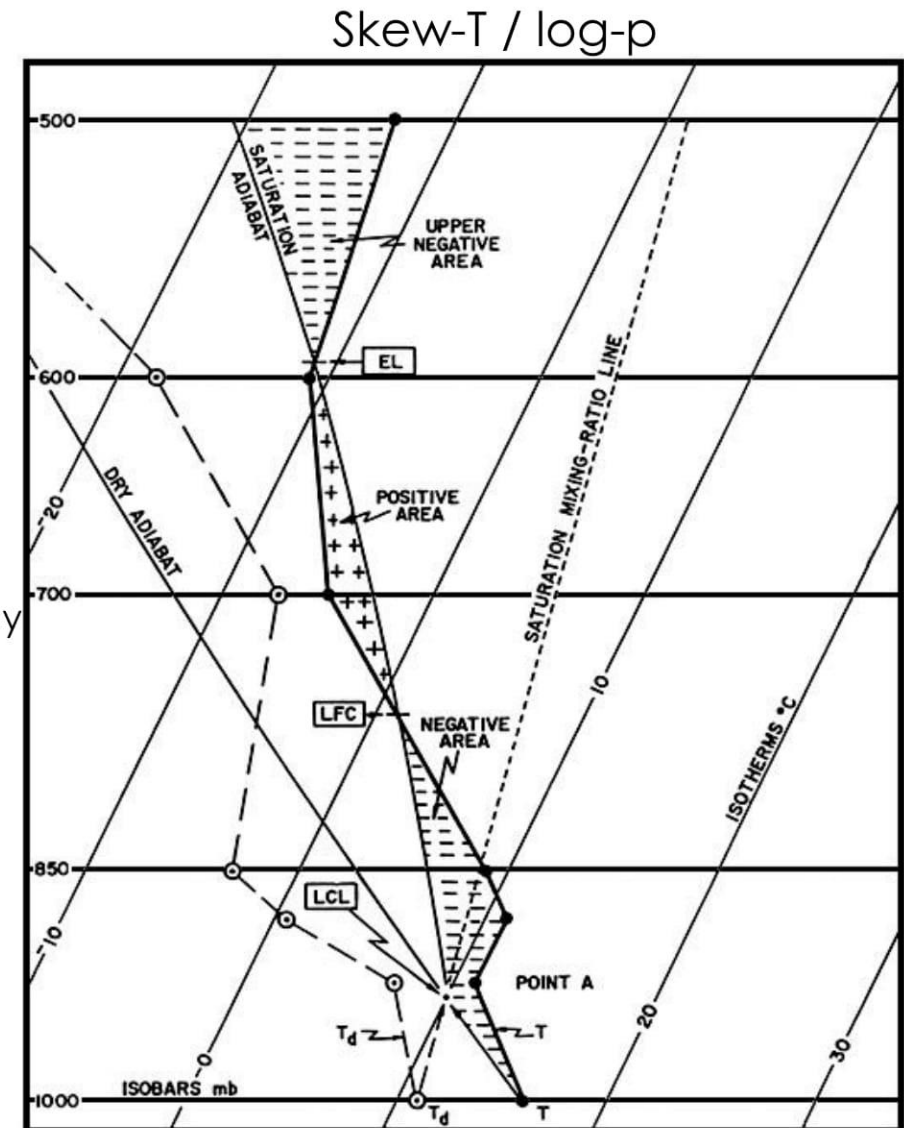
- Convective Inhibition (CIN)

$$CIN = \int_{z_{bottom}}^{z_{top}} g \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) dz$$

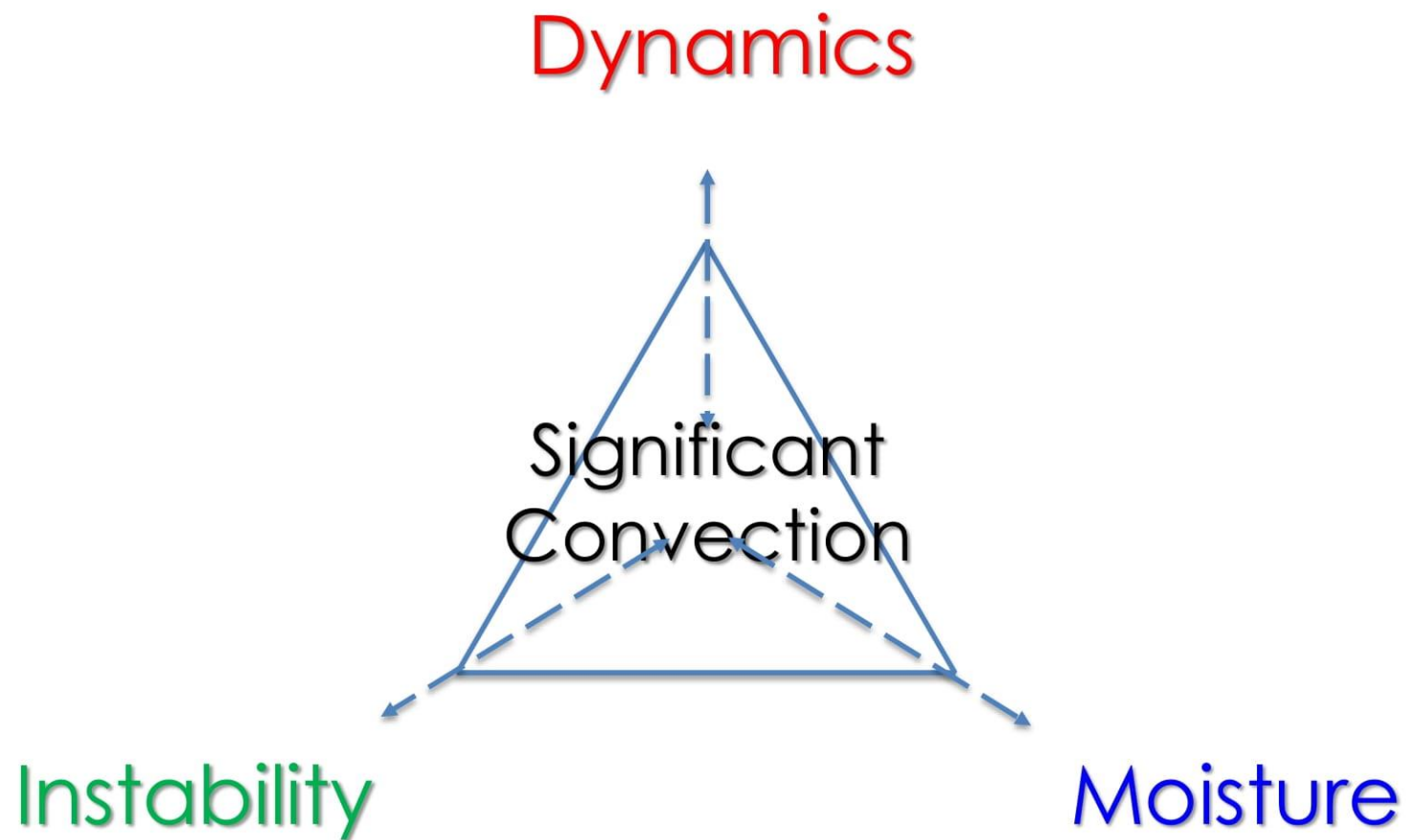
z_{top} : LFC
 z_{bottom} : surface

- Bulk Richardson Number

- $BRN = CAPE / (0.5 * (\text{shear differential})^2)$

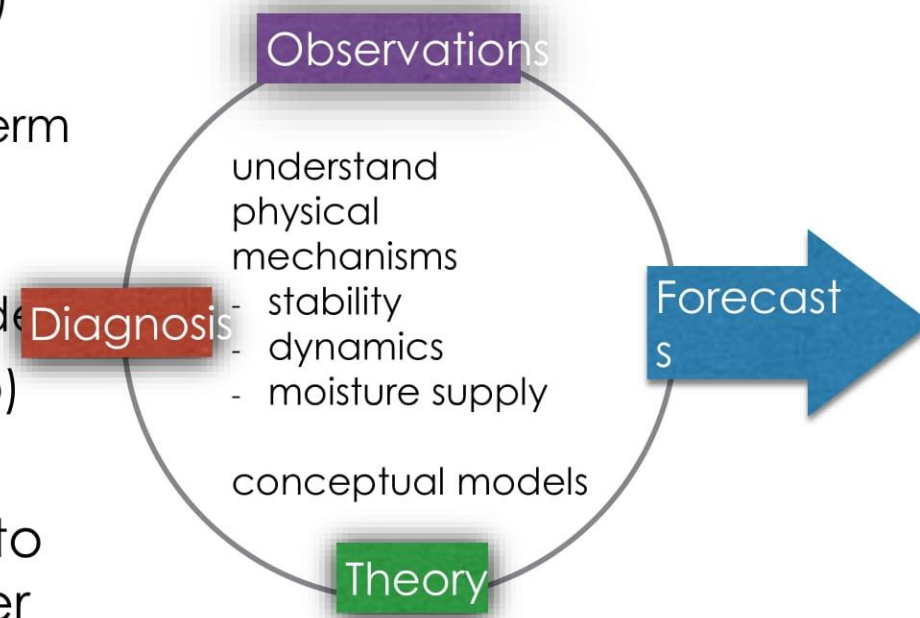


Perspectives of predicting high-impact convective weather processes



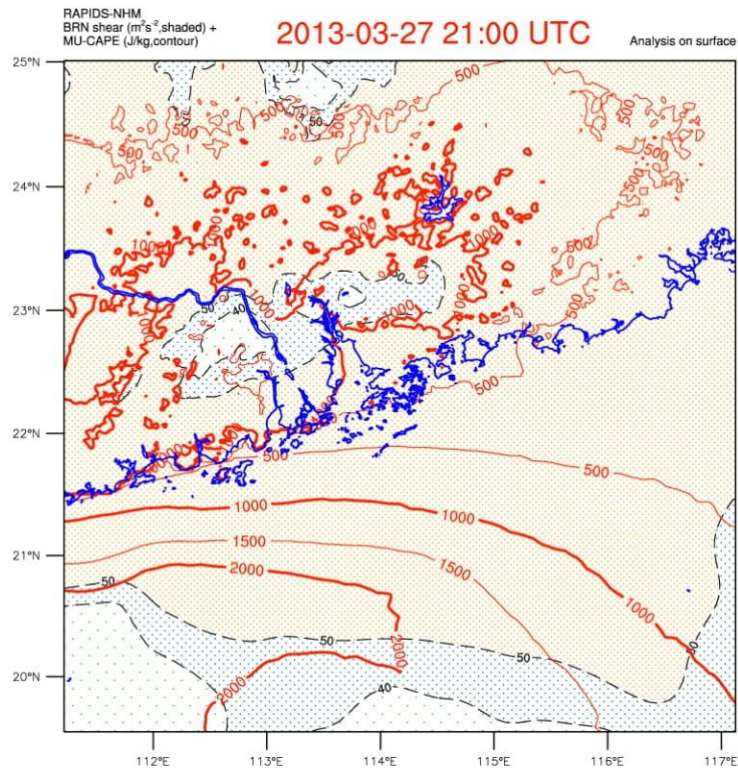
Rule of thumbs in severe weather forecasting

- **Understanding** of physical mechanisms about initiation movement and development
 - interpretation of radar sequence (local to regional mosaic) and satellite products
 - deduce possible supporting factors from analysis or short-term forecast products from NWP model on dynamical and thermodynamics factors
 - model QPF are results from many processes in NWP model
 - jumpiness issues (→ EPS consensus diagnostics may help)
- **Diagnosis** of model analysis/forecasts and connecting to conceptual models of heavy rain or mesoscale weather processes
- **Verification** - subjective and objective metrics assist in understanding accuracy, confidence and jumpiness of model forecasts

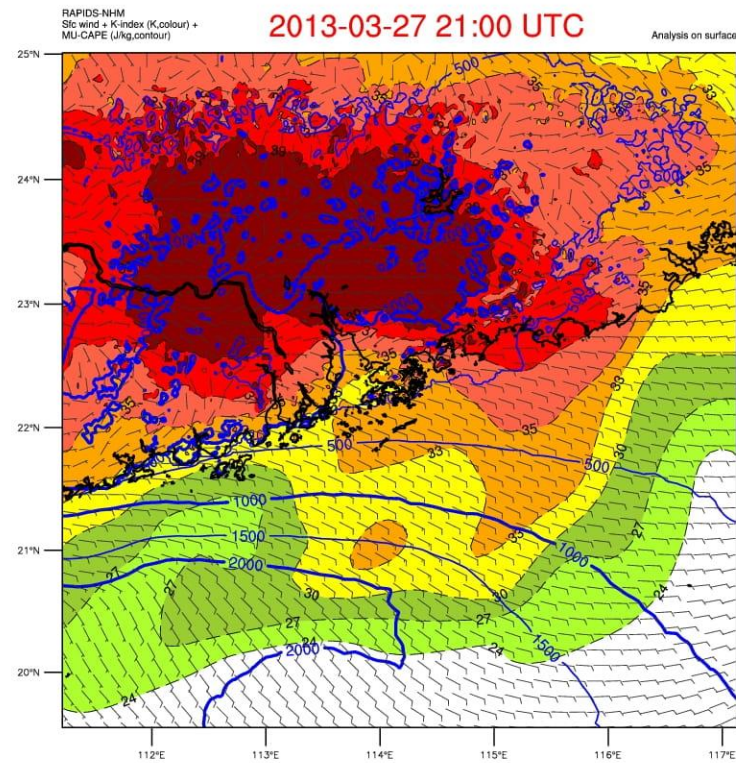


Mesoscale Analysis Diagnostics from RAPIDS-NHM Hourly Analysis

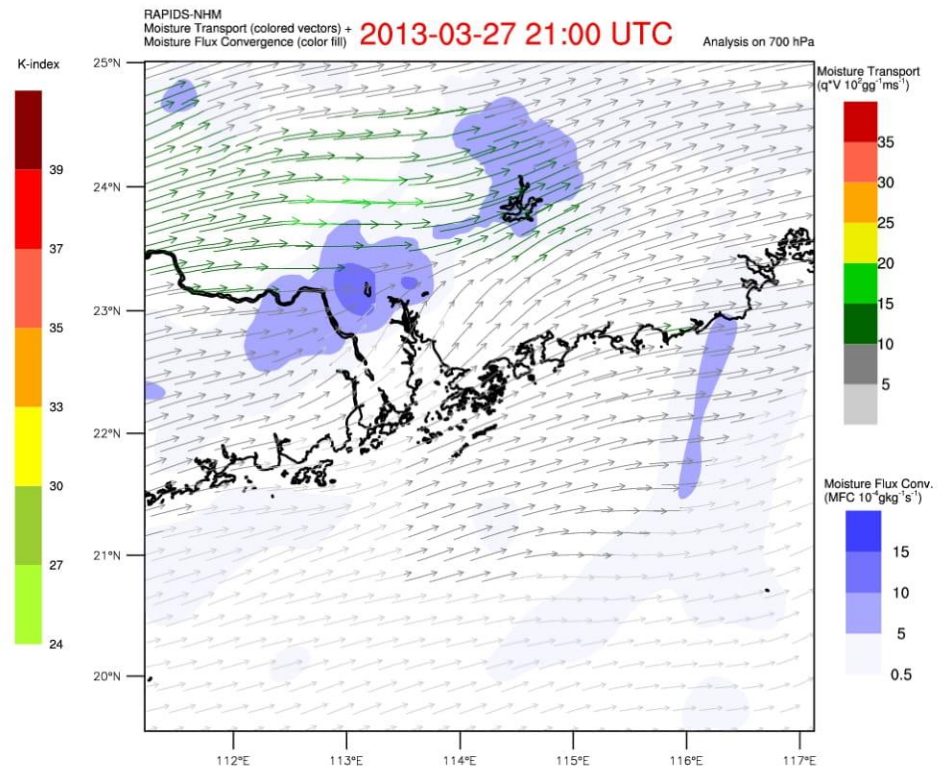
- Keep close monitoring on current and changes in synoptic and mesoscale characteristics, instability, and moisture conditions



Bulk-Richardson Number Shear
most-unstable layer CAPE (MU-CAPE)

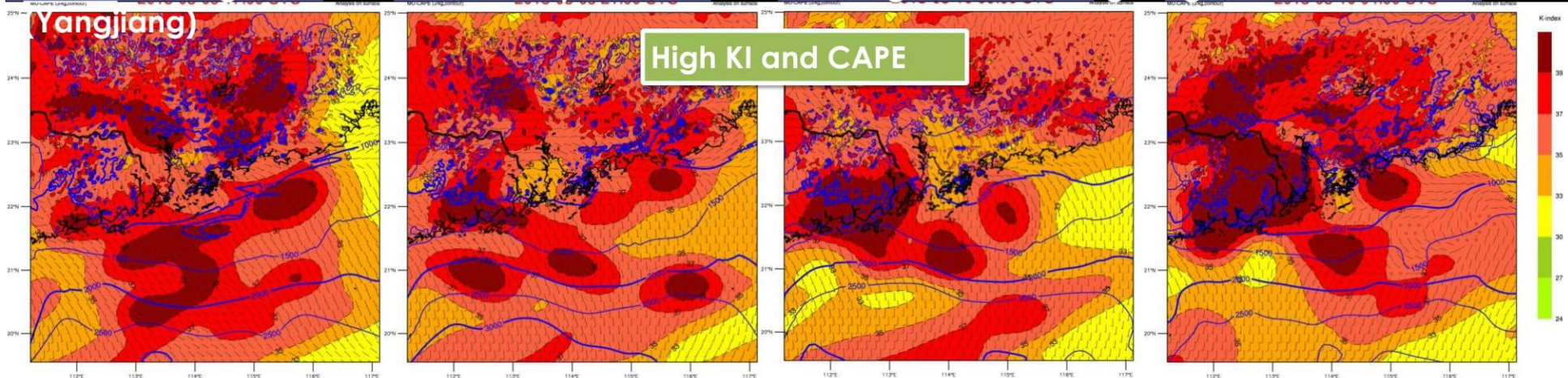
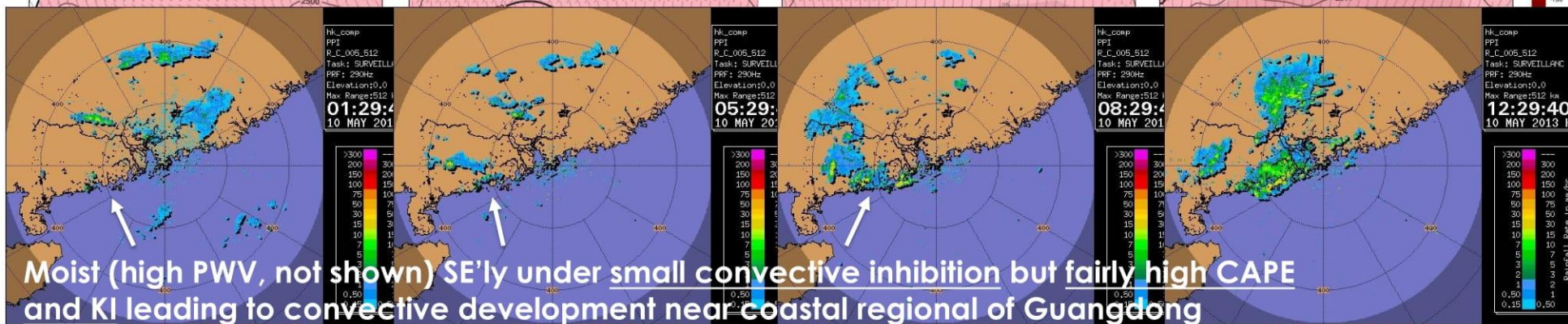
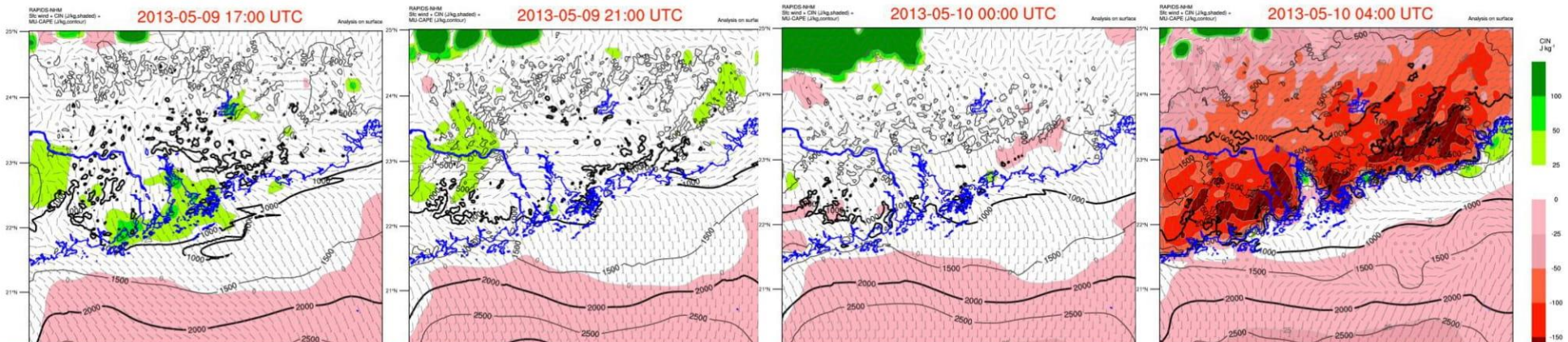


K-index and
most-unstable layer CAPE (MU-CAPE)



Moisture transport ($\sim qV$)
moisture flux convergence $\nabla \cdot (qV)$

RAPIDS-NHM Hourly Analysis of CIN, CAPE & KI



25 May 2020



Amber 黃

10:05-10:35am



Red 紅

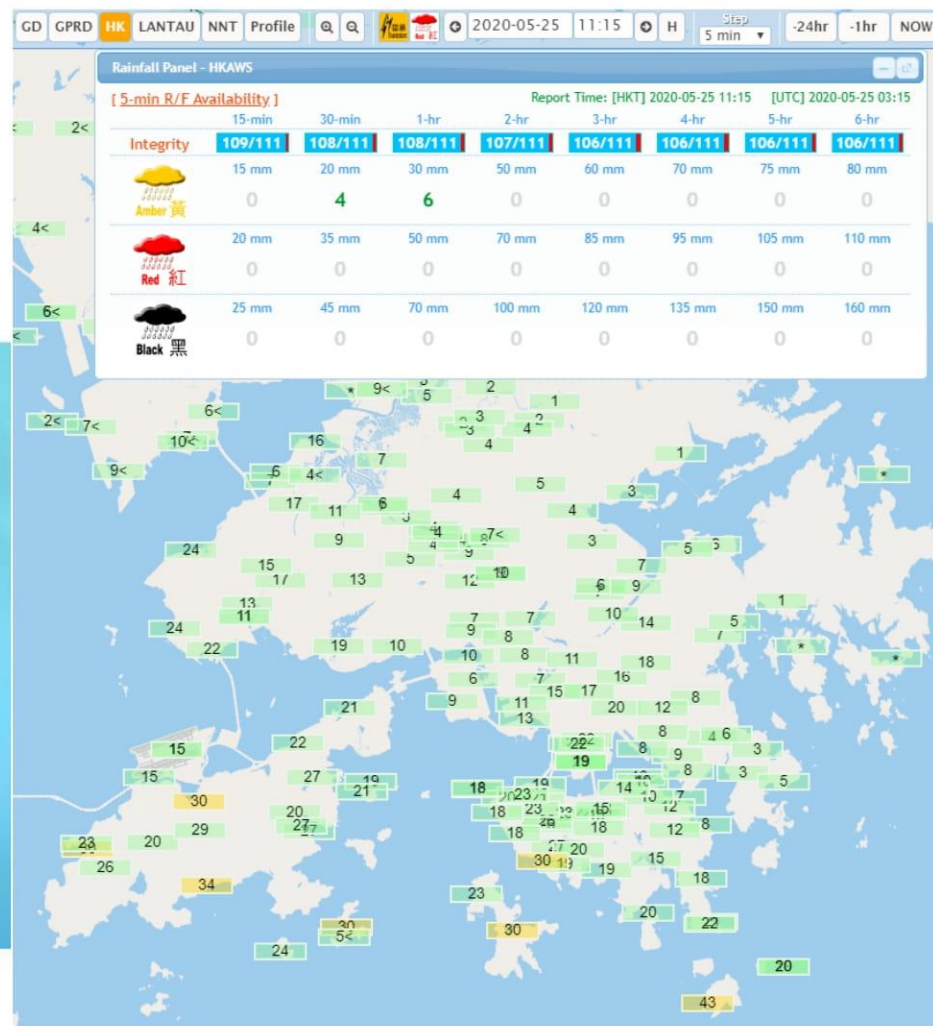
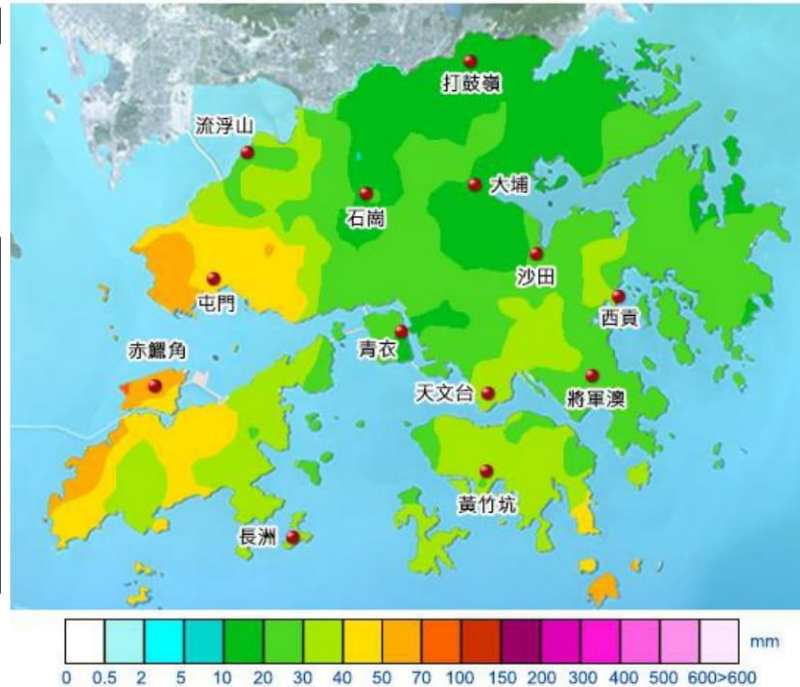
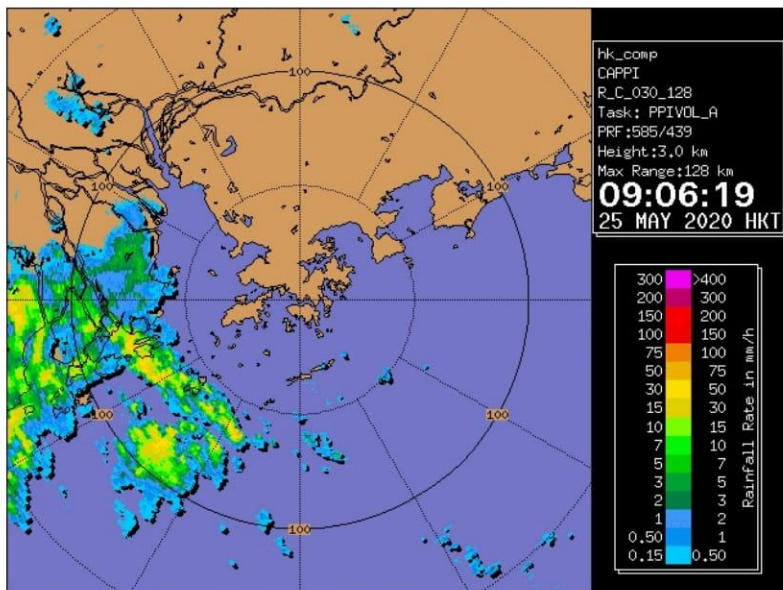
10:35-11:40am



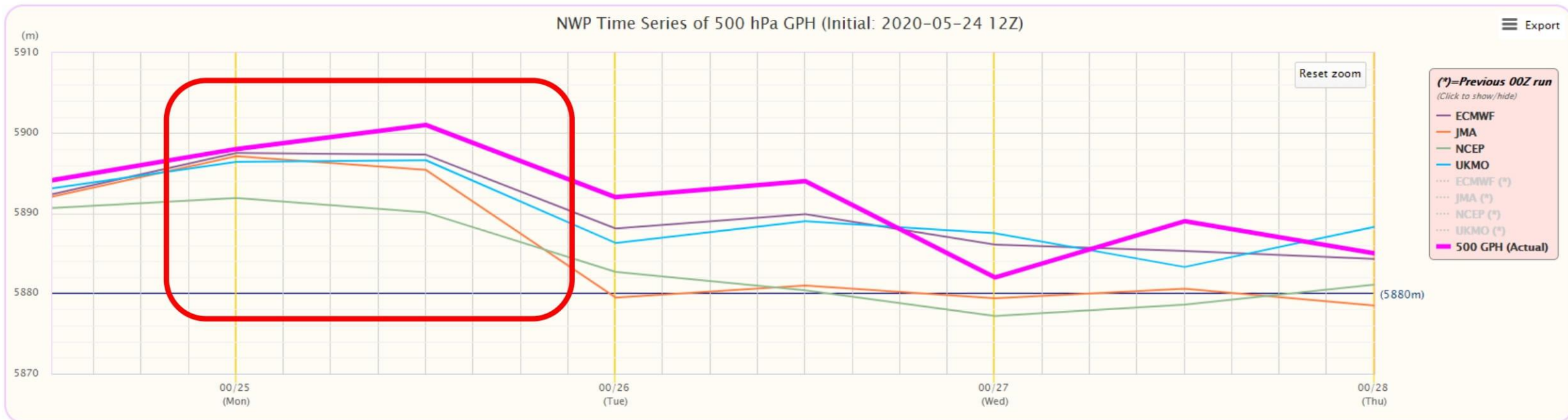
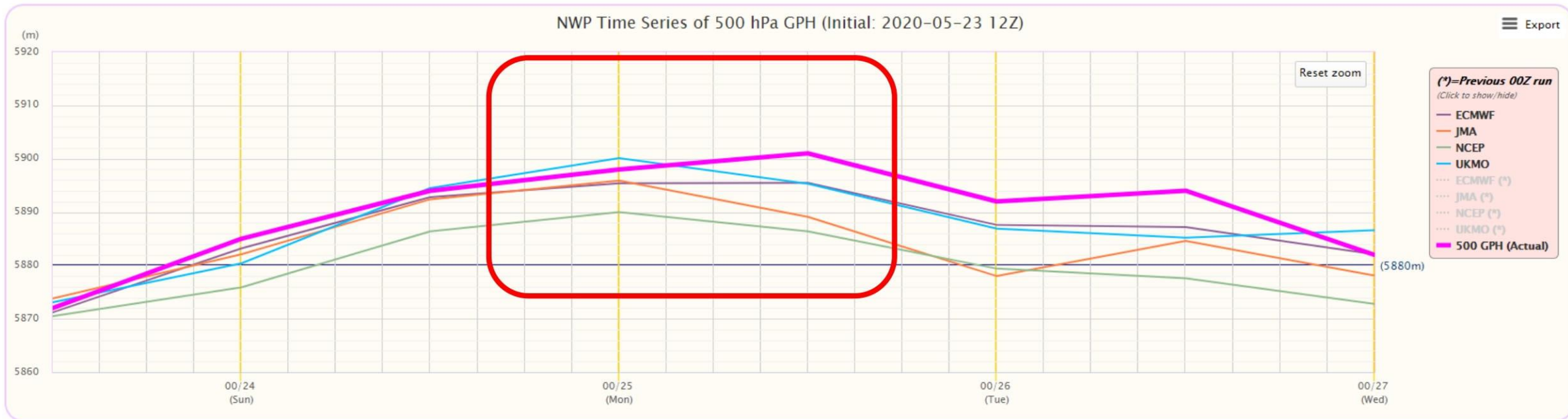
Amber 黃

11:40-12:40am

2020年5月25日的總雨量(基於雨量計及雷達數據)



NWP models forecast increase in 500 hPa GPH



With more recent initial conditions, NWP models (global and mesoscale) suggested less rainfall be more probable

24 (Sun) | 25 (Mon) | 26 (Tue) | 27 (Wed) | 28 (Thu) | 29 (Fri) | 30 (Sat) | 31 (Sun) | 01 (Mon) | 02 (Tue)

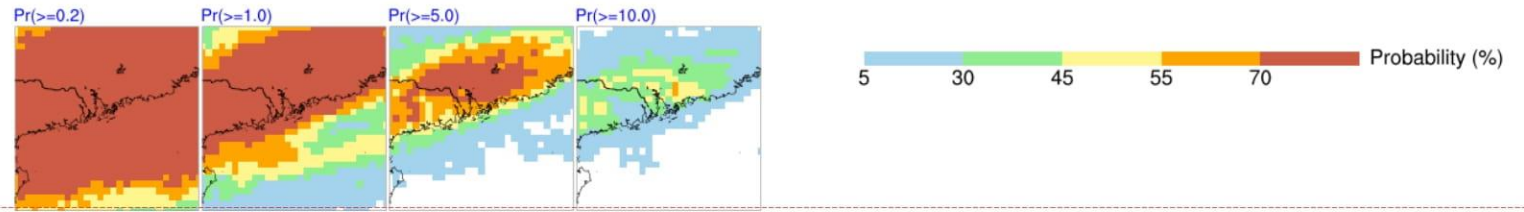
Forecast Date : 25 May 2020 (Mon)

Model	Grid / Type	Base Time											
		24/06 Z	24/00 Z	23/18 Z	23/12 Z	23/06 Z	23/00 Z	22/18 Z	22/12 Z	22/06 Z	22/00 Z	21/18 Z	21/12 Z
ECMWF	Average	6.1	8.0	3.2	9.2	11.3	21.7	15.3	13.1	93.3	11.5	13.1	7.6
KMA	Average		4.2		25.0		8.4		8.9		18.3		5.9
JMA	Average	2.0	1.8	2.1	5.4	8.9	7.7	8.5	6.2	5.5	6.6	7.0	3.9
NCEP	Average	1.7	1.4	4.8	8.0	3.6	4.3	16.7	20.0	18.4	13.5	32.4	45.2
UKMO	Average		3.1				19.8		21.1		42.7		22.1
AAMC-WRF	Average		8.2		12.0		17.3	12.4	13.4	12.3	18.2		
ECEPS	50%-tile		8.7		10.7		13.2		14.5		12.1		8.0
ECEPS	75%-tile		12.9		15.1		22.4		22.9		20.3		15.3

Can Ensemble Prediction System(s) help?

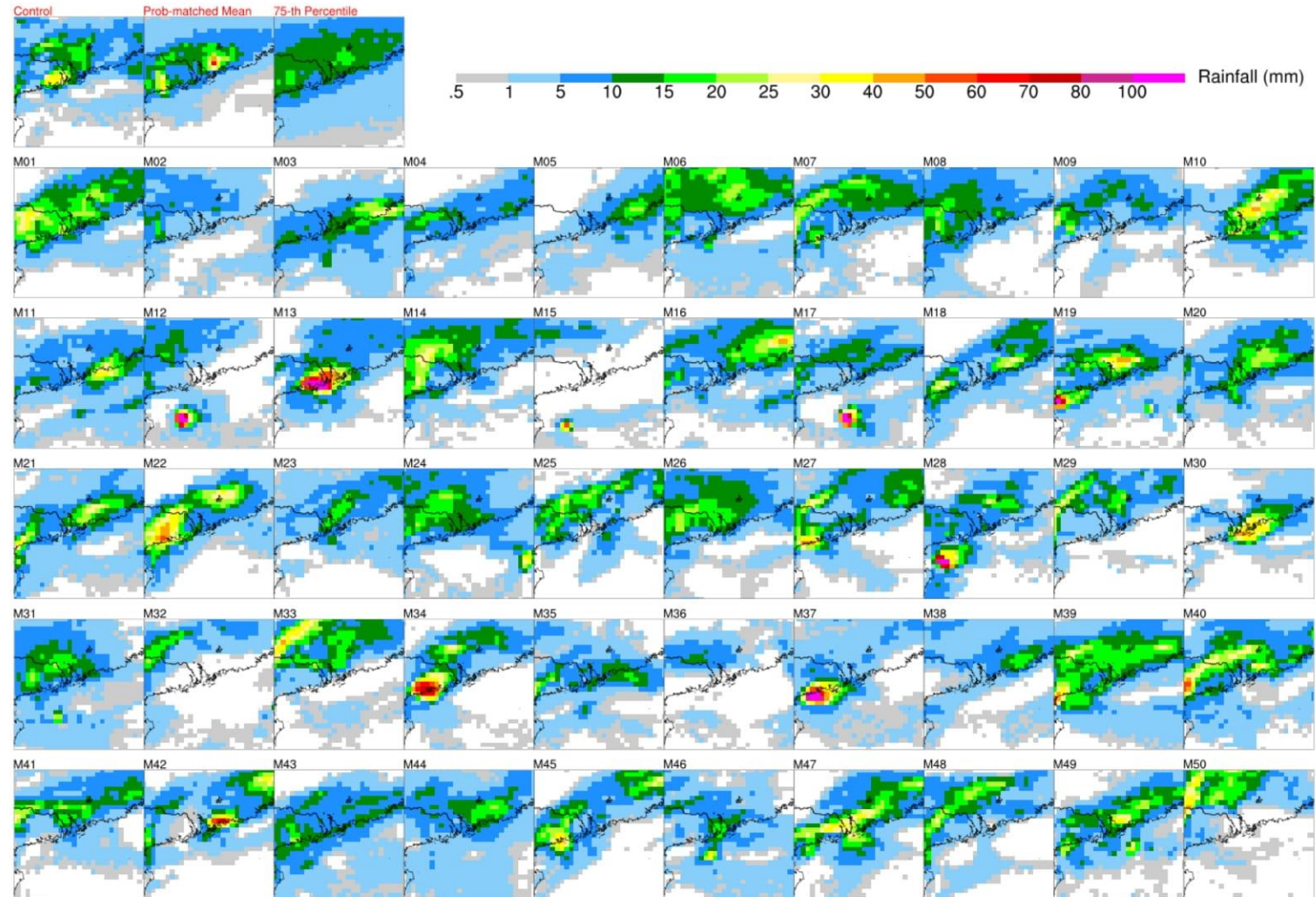
Probability of 3-h/6-h rainfall

≥ 0.2 ≥ 1.0 ≥ 5.0 ≥ 10.0



Control	Probability Matching Ensemble Mean	75-th Percentile
---------	------------------------------------	------------------

50 EPS Members



ECMWF EPS
3-h accumulated rainfall

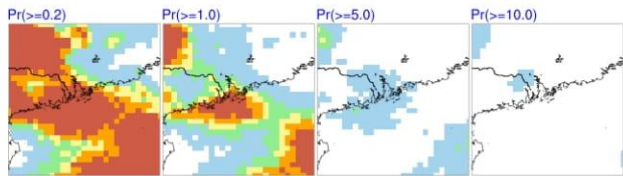
2020-05-25 00:00 UTC (Mon)

T+24 h forecast from
2020-05-24 00:00 UTC

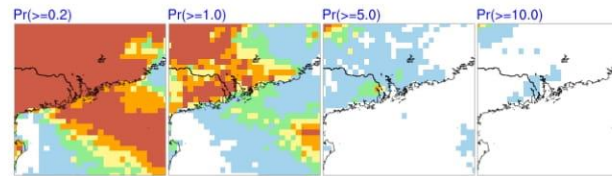
ECMWF EPS
3-h accumulated rainfall

2020-05-25 06:00 UTC (Mon)

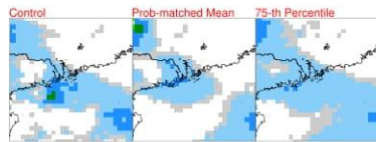
T+30 h forecast from
2020-05-24 00:00 UTC



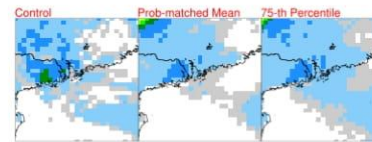
5 30 45 55 70 Probability (%)



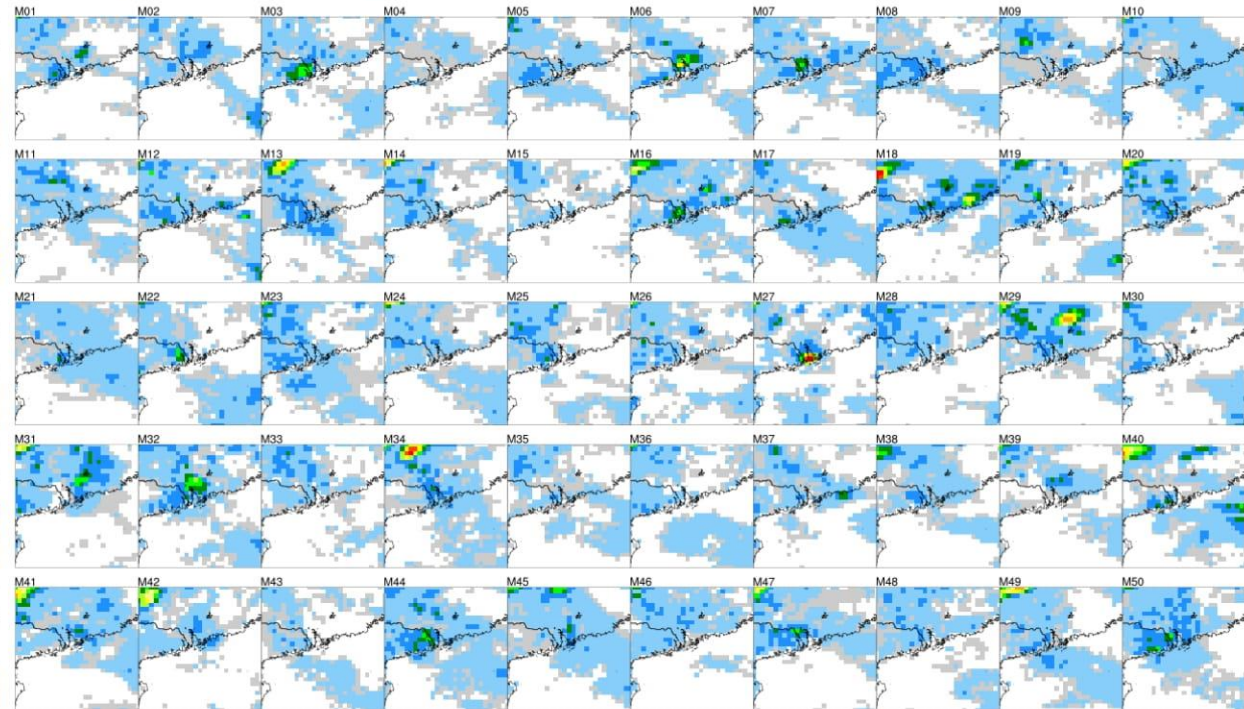
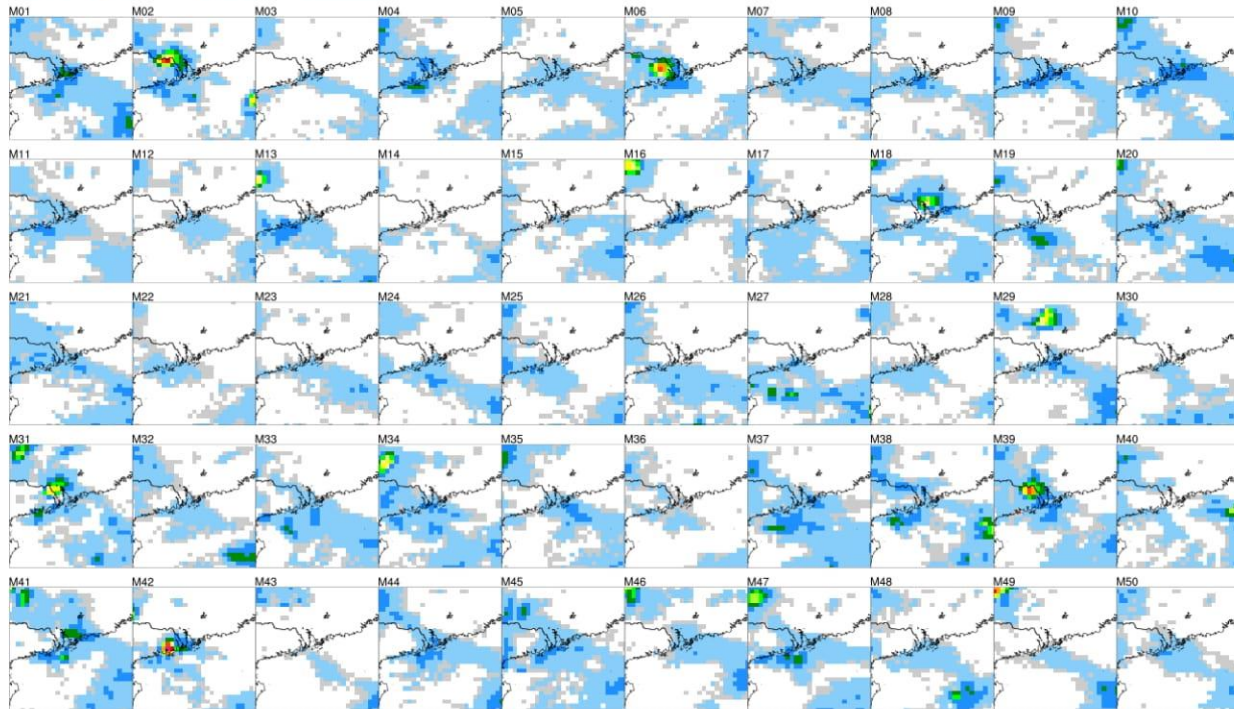
5 30 45 55 70 Probability (%)



.5 1 5 10 15 20 25 30 40 50 60 70 80 100 Rainfall (mm)



.5 1 5 10 15 20 25 30 40 50 60 70 80 100 Rainfall (mm)





With more recent initial conditions, NWP models (global and mesoscale) and EPS suggested less rainfall be more probable

PoP (heavy) < 60%

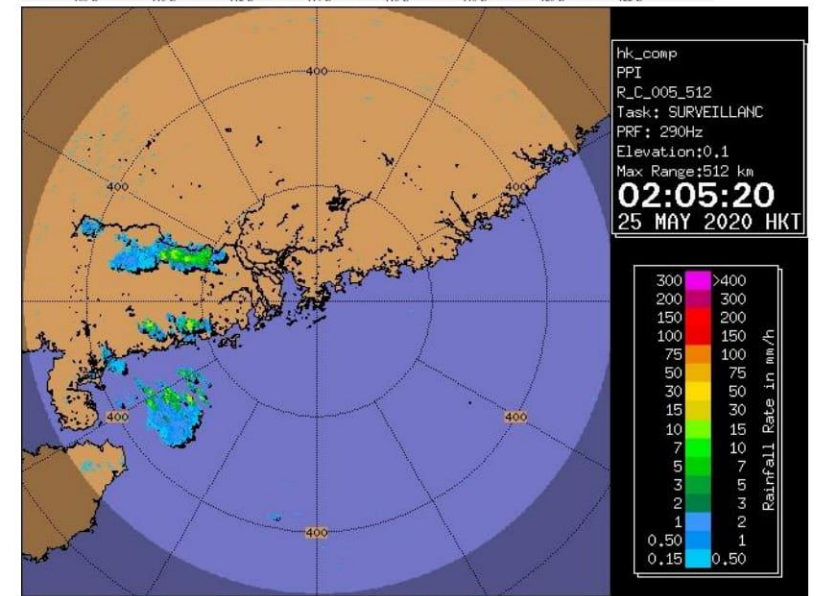
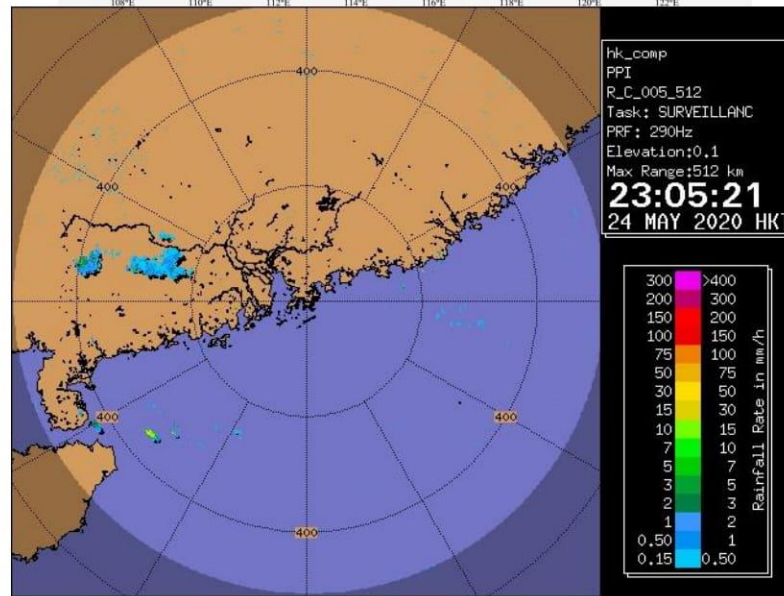
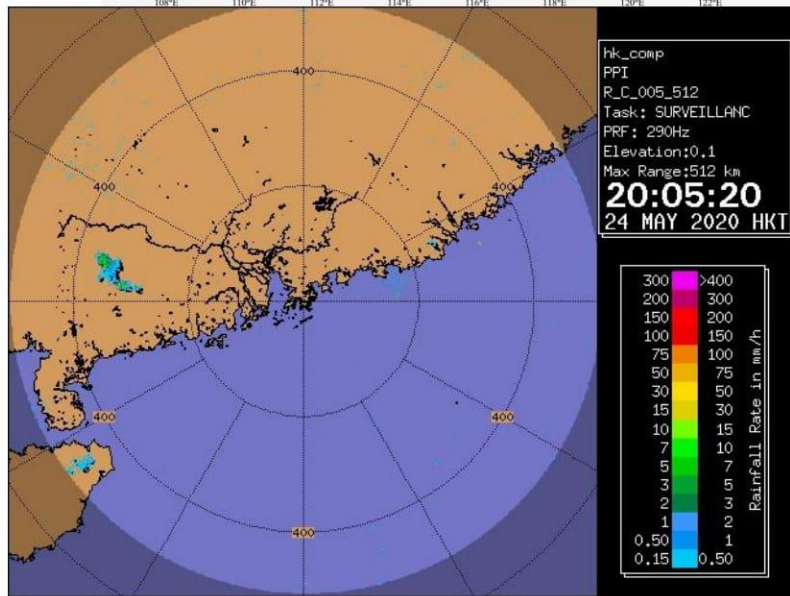
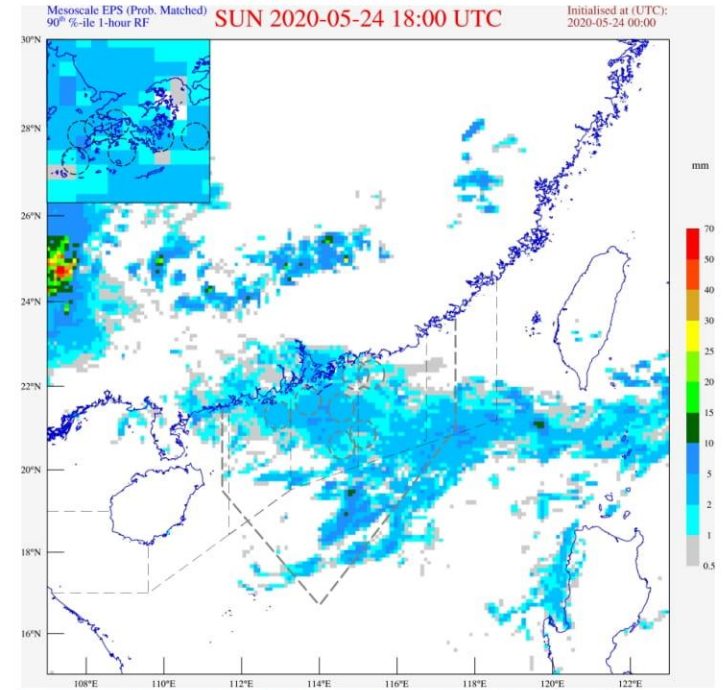
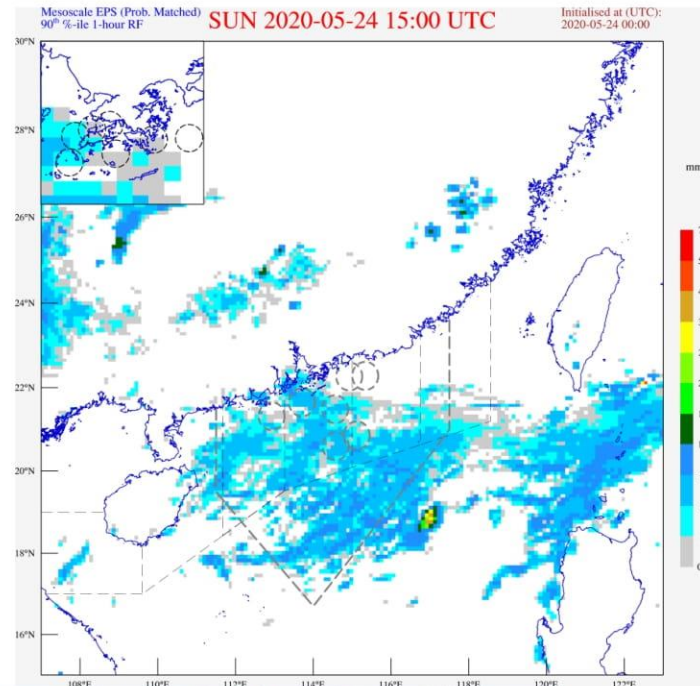
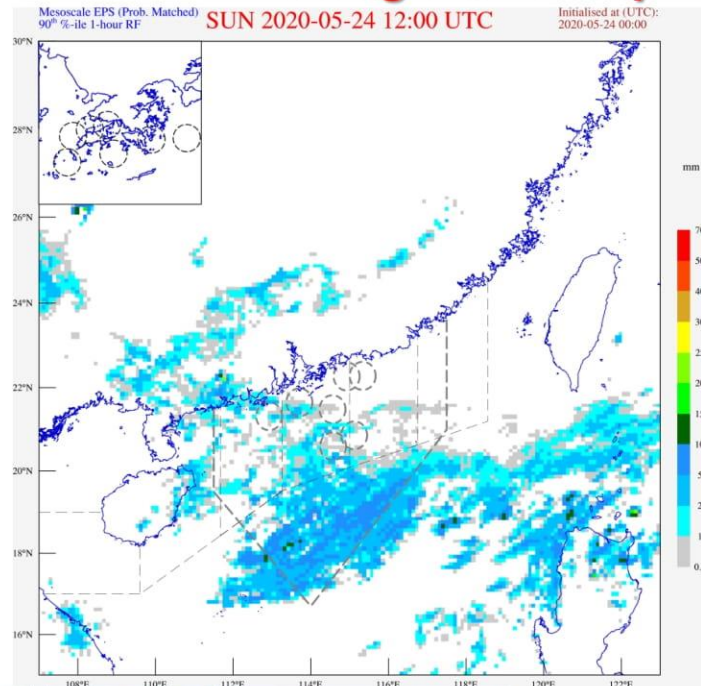
24 (Sun) 25 (Mon) 26 (Tue) 27 (Wed) 28 (Thu) 29 (Fri) 30 (Sat) 31 (Sun) 01 (Mon) 02 (Tue)

Forecast Date : 25 May 2020 (Mon)

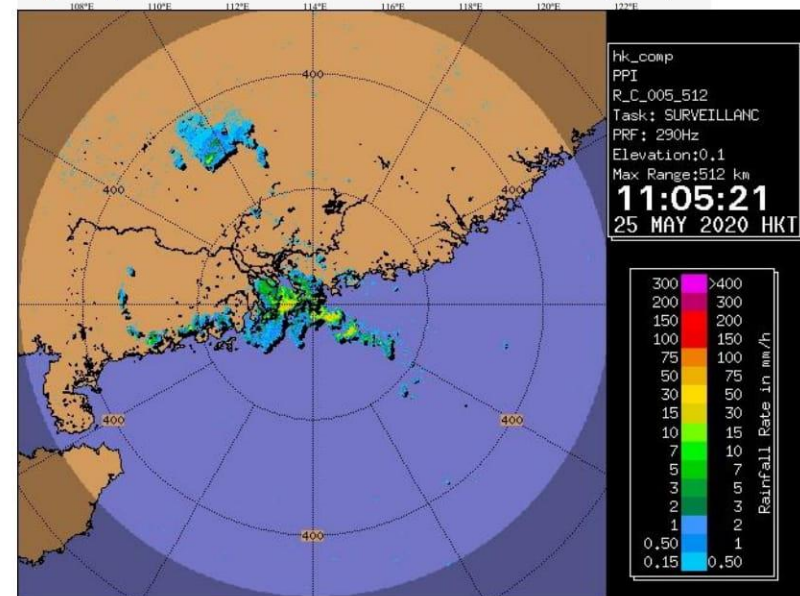
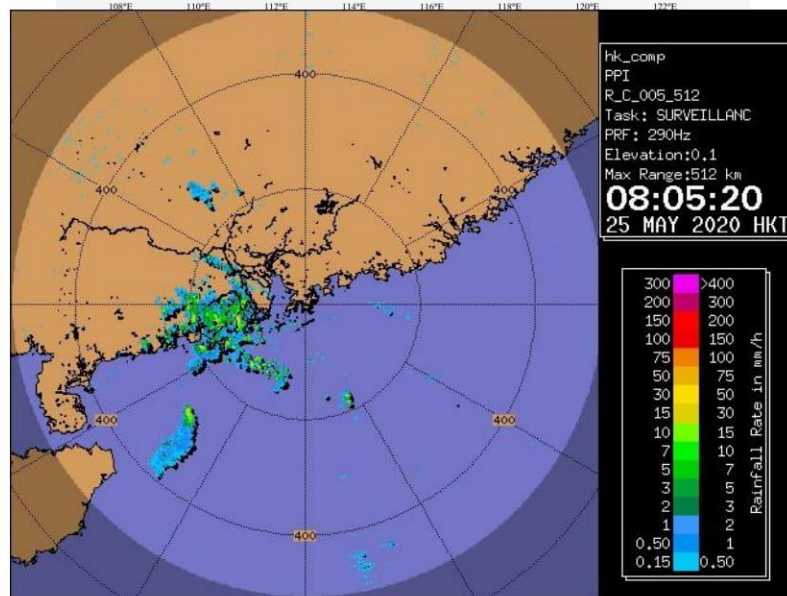
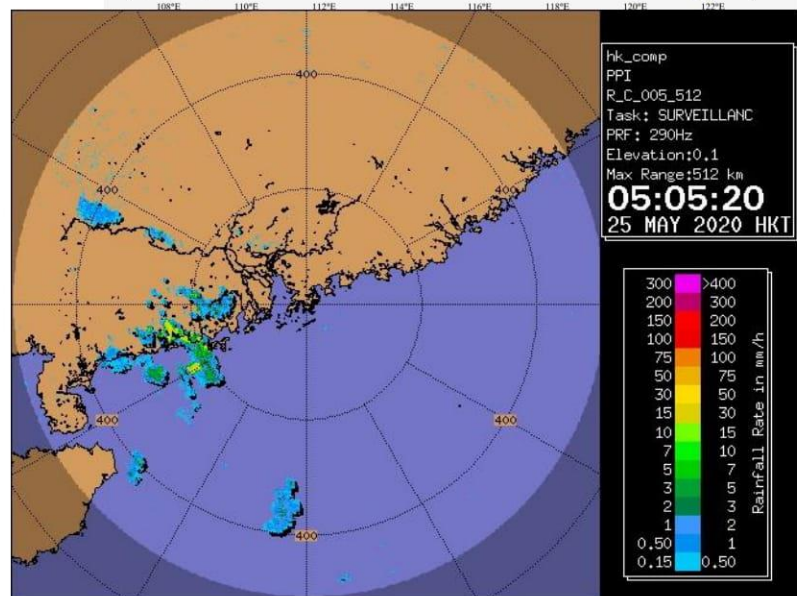
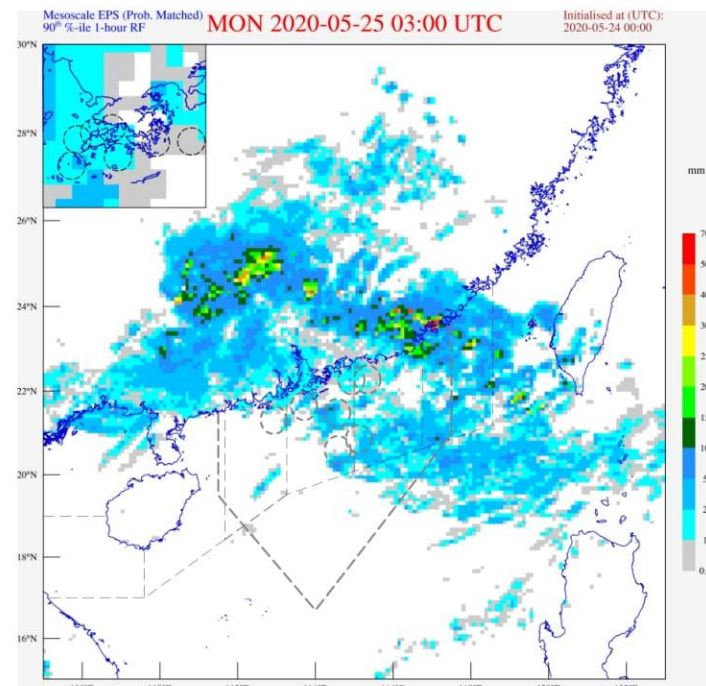
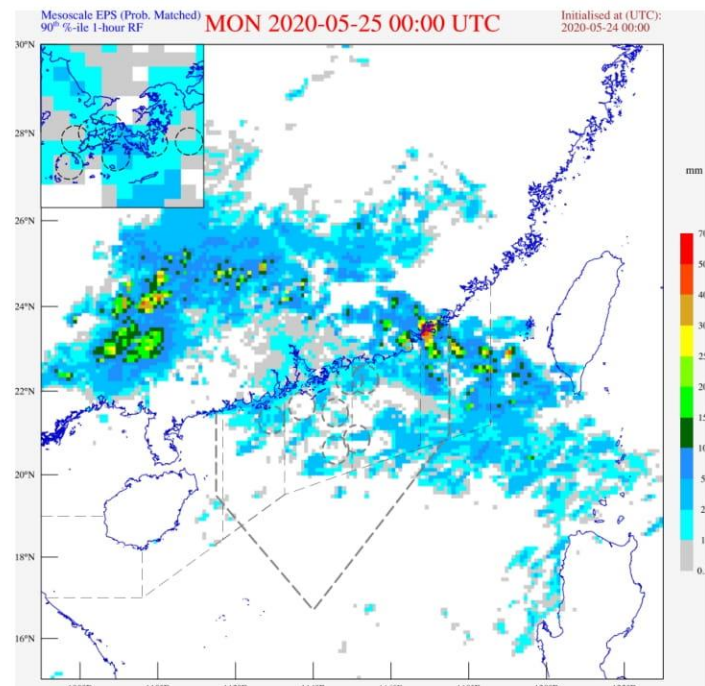
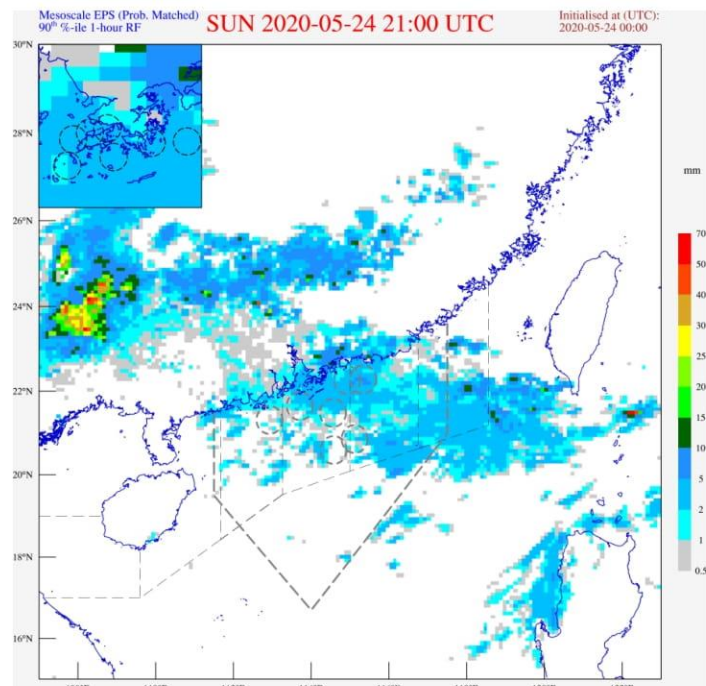
Model	Grid / Type	Base Time											
		24/06 Z	24/00 Z	23/18 Z	23/12 Z	23/06 Z	23/00 Z	22/18 Z	22/12 Z	22/06 Z	22/00 Z	21/18 Z	21/12 Z
ECMWF	Average	6.1	8.0	3.2	9.2	11.3	21.7	15.3	13.1	93.3	11.5	13.1	7.6
KMA	Average		4.2		25.0		8.4		8.9		18.3		5.9
JMA	Average	2.0	1.8	2.1	5.4	8.9	7.7	8.5	6.2	5.5	6.6	7.0	3.9
NCEP	Average	1.7	1.4	4.8	8.0	3.6	4.3	16.7	20.0	18.4	13.5	32.4	45.2
UKMO	Average		3.1				19.8		21.1		42.7		22.1
AAMC-WRF	Average		8.2		12.0		17.3	12.4	13.4	12.3	18.2		
ECEPS	50%-tile		8.7		10.7		13.2		14.5		12.1		8.0
ECEPS	75%-tile		12.9		15.1		22.4		22.9		20.3		15.3

25/05 Mon	Moderate or above 	Heavy or above 
2020052412Z	13	5
2020052400Z	44	19
2020052312Z	57	30
2020052300Z	70	47
2020052212Z	77	53
2020052200Z	64	41
2020052112Z	42	24
2020052100Z	41	25
2020052012Z	56	33
2020052000Z	40	28
2020051912Z	51	36
2020051900Z	53	45
2020051812Z	60	49
2020051800Z	67	55
2020051712Z	55	43
2020051700Z	56	44
2020051612Z	57	43
2020051600Z	47	35
2020051512Z	46	30
2020051500Z	37	23

Mesoscale EPS hinted a band of rainfall would develop and approach from SW, but **false** timing & intensity

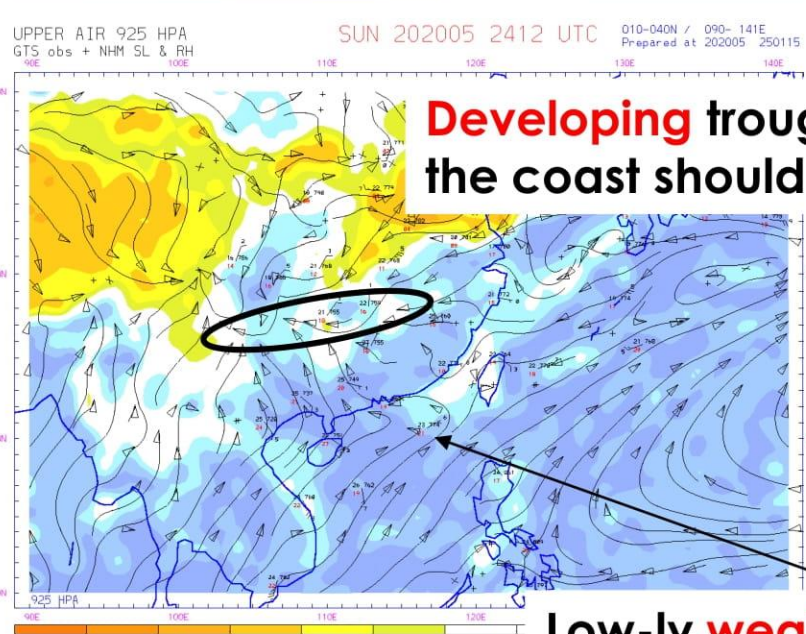
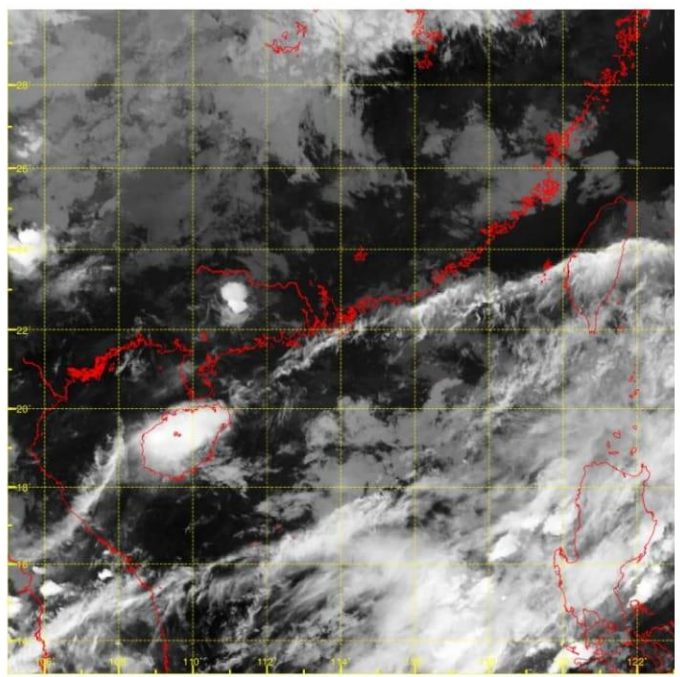
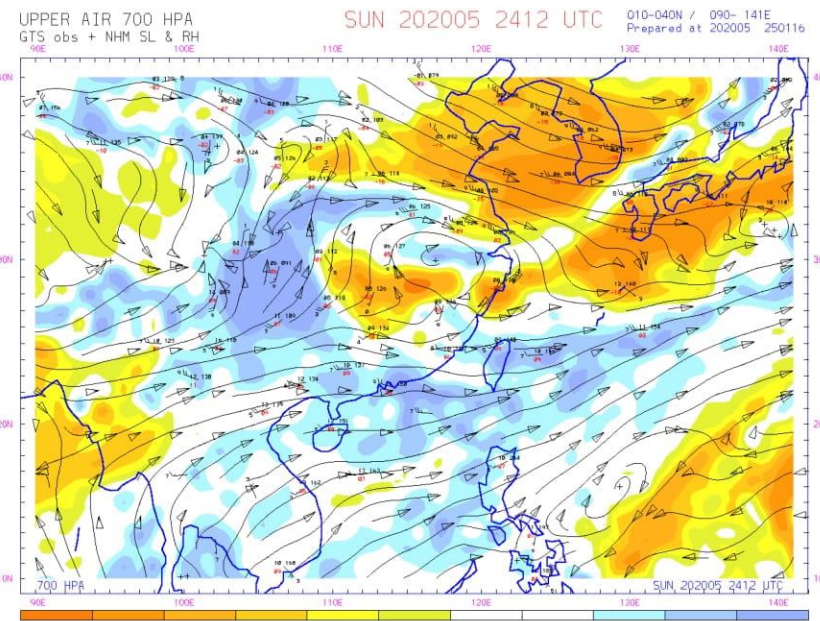
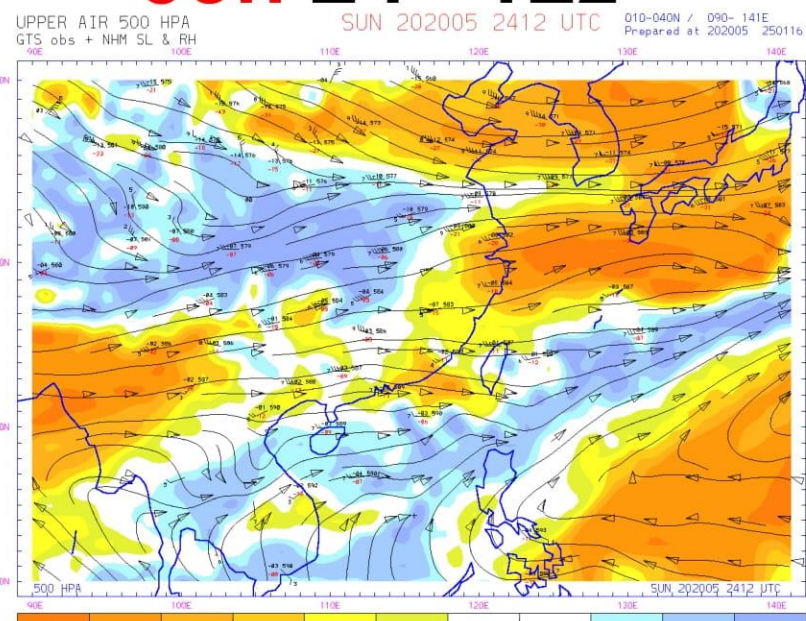
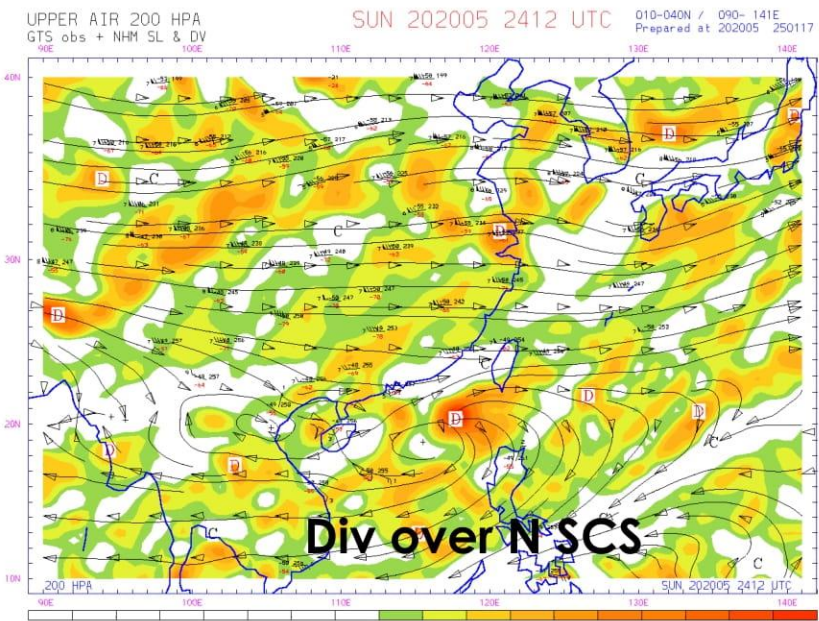


Mesoscale EPS hinted a band of rainfall would come from SW, but **false timing & intensity**

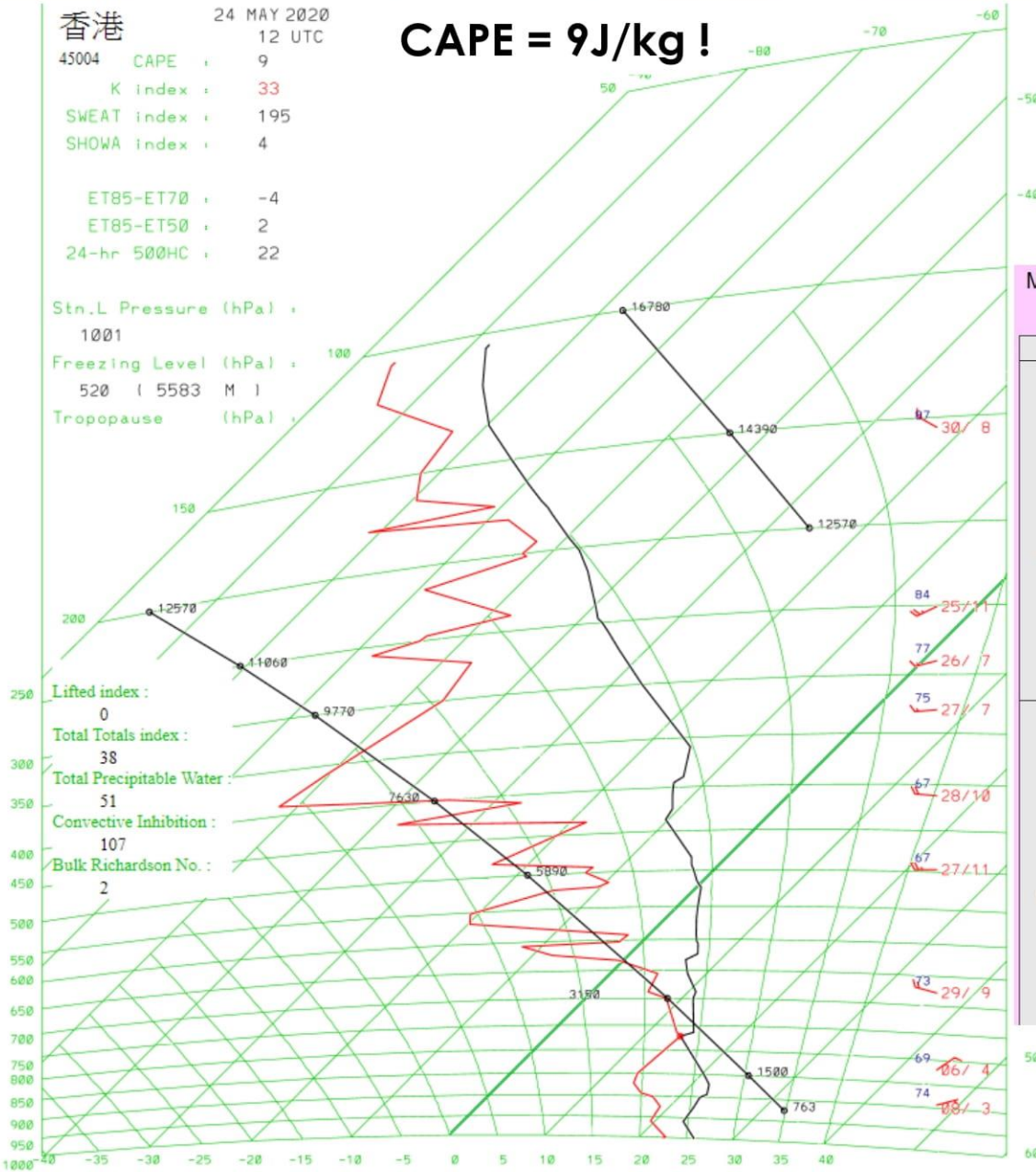


What's Wrong ?

Sun 24th 12Z

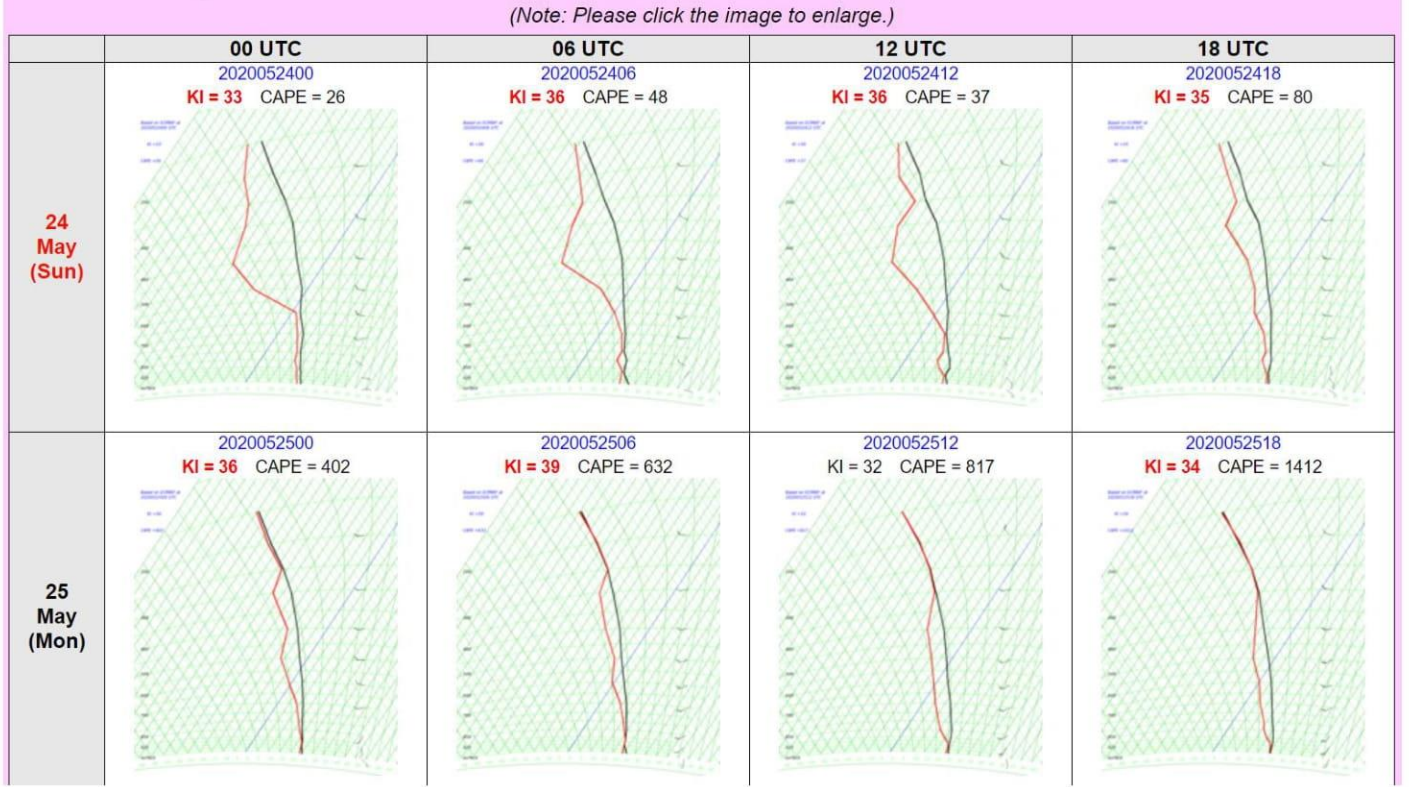


Low-lv weak trough over N SCS



Some hints from model forecast tephigram on decrease in

Model : 0.125 deg ECMWF Model base time : 2020052400 UTC

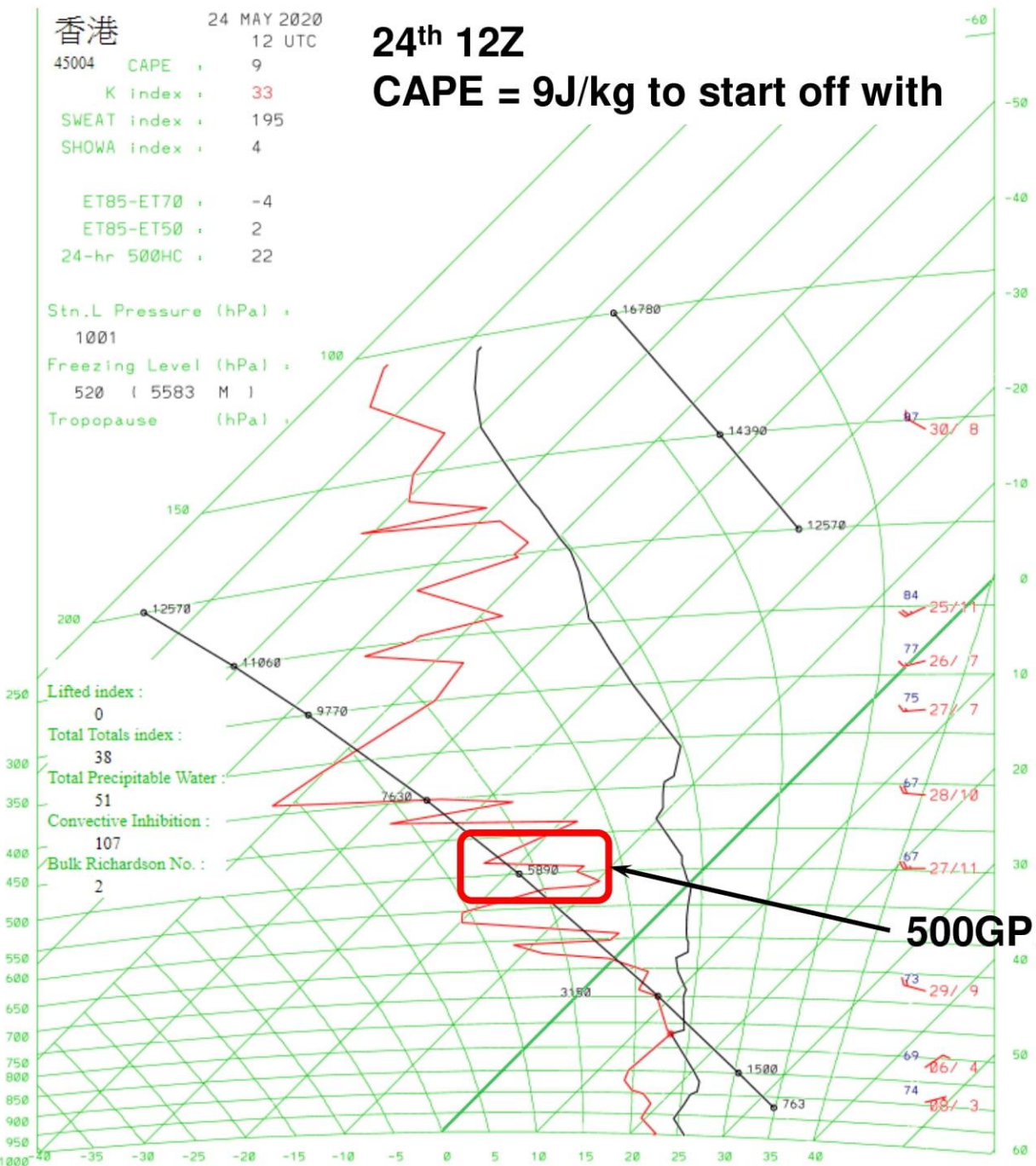


香港 24 MAY 2020
 45004 CAPE : 9
 K index : 33
 SWEAT index : 195
 SHOWA index : 4
 ET85-ET70 : -4
 ET85-ET50 : 2
 24-hr 500HC : 22

24th 12Z
CAPE = 9J/kg to start off with

Stn.L Pressure (hPa) : 1001
 Freezing Level (hPa) : 520 (5583 M)
 Tropopause (hPa) :

Lifted index : 0
 Total Totals index : 38
 Total Precipitable Water : 51
 Convective Inhibition : 107
 Bulk Richardson No. : 2

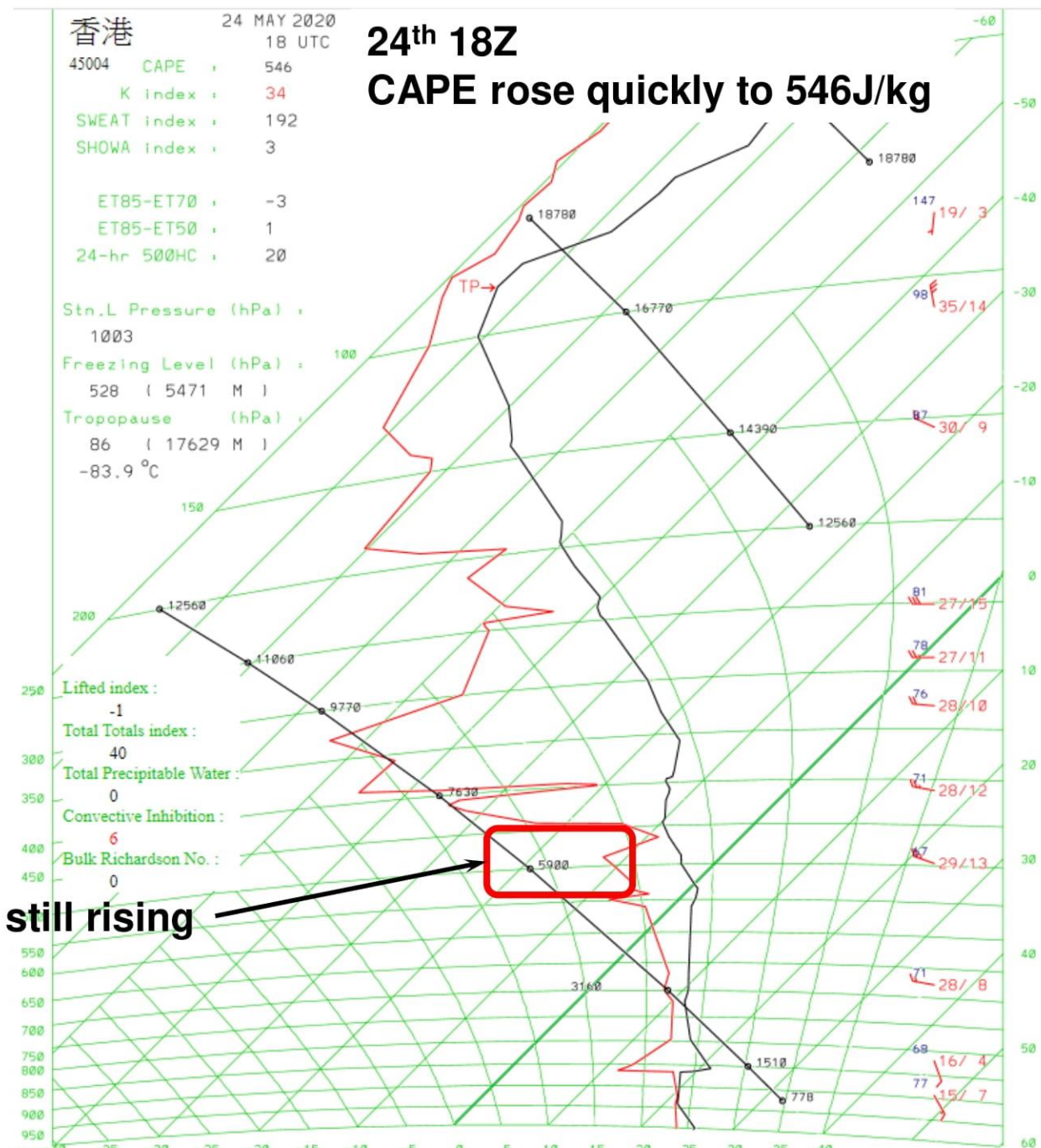


香港 24 MAY 2020
 45004 CAPE : 546
 K index : 34
 SWEAT index : 192
 SHOWA index : 3
 ET85-ET70 : -3
 ET85-ET50 : 1
 24-hr 500HC : 20

24th 18Z
CAPE rose quickly to 546J/kg

Stn.L Pressure (hPa) : 1003
 Freezing Level (hPa) : 528 (5471 M)
 Tropopause (hPa) : 86 (17629 M)
 -83.9 °C

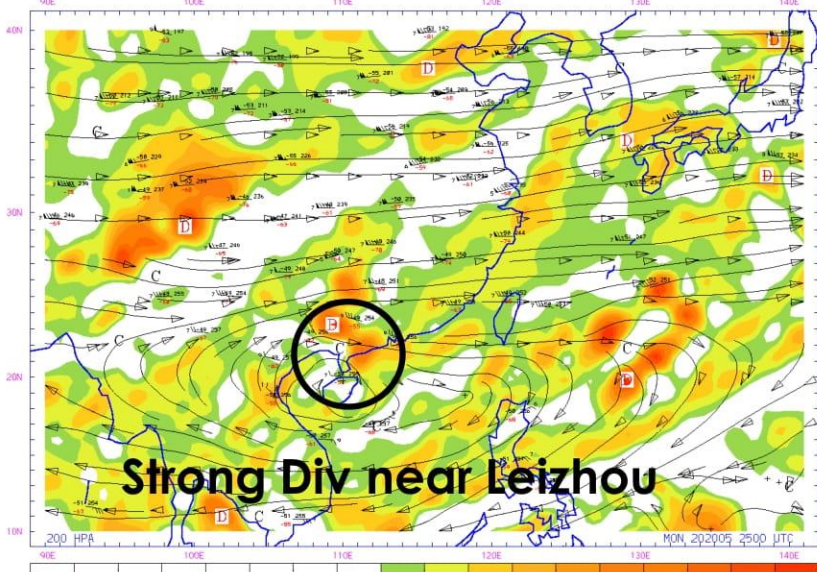
Lifted index : -1
 Total Totals index : 40
 Total Precipitable Water : 0
 Convective Inhibition : 6
 Bulk Richardson No. : 0



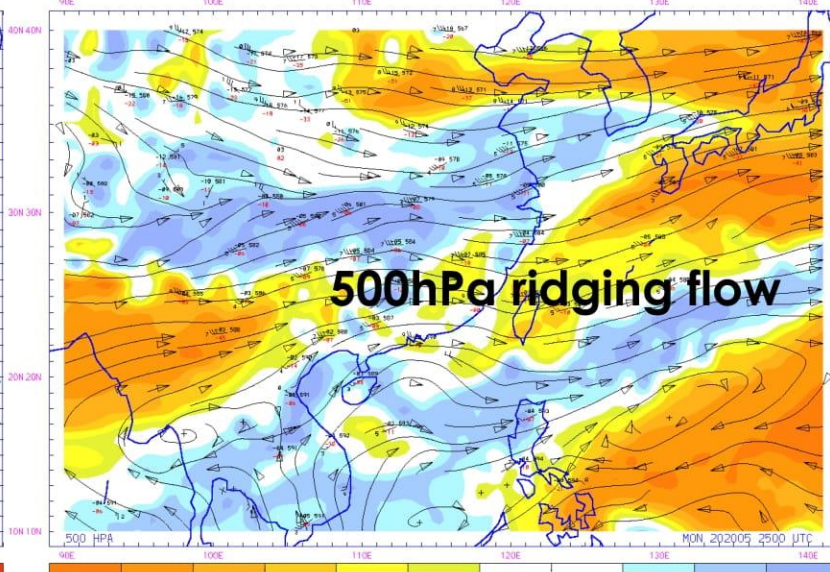
500GPH still rising

Mon 25th 00Z

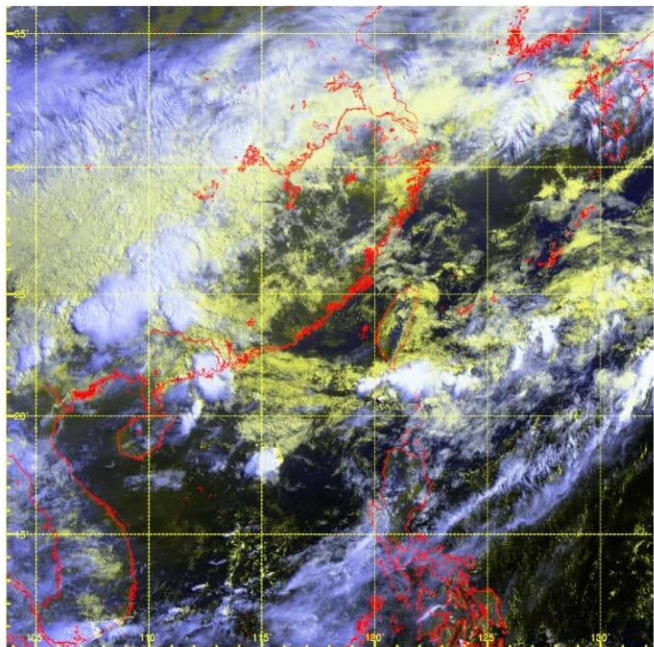
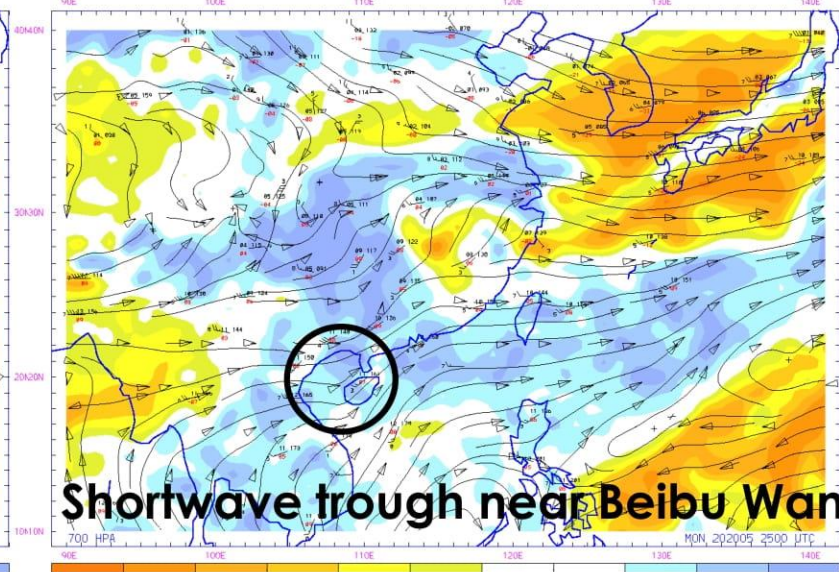
UPPER AIR 200 HPA
GTS obs + NHM SL & DV
MON 202005 2500 UTC
010-040N / 090-141E
Prepared at 202005 251317



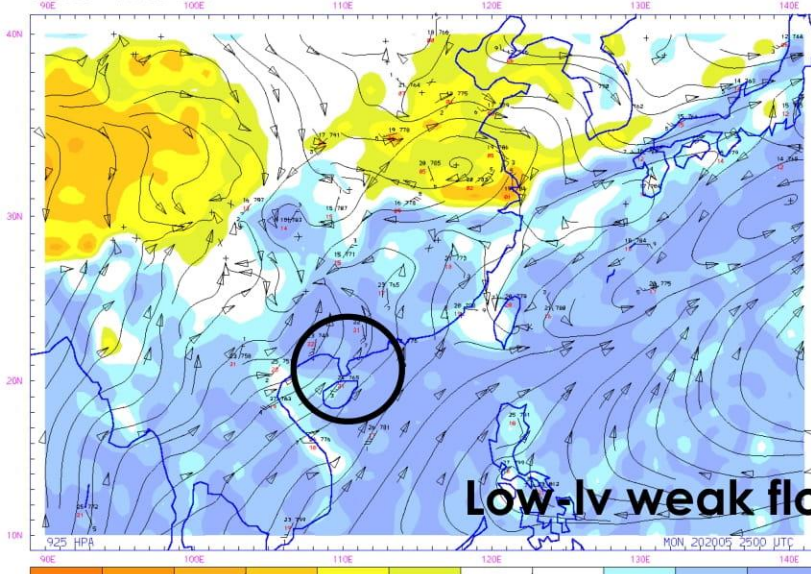
UPPER AIR 500 HPA
GTS obs + NHM SL & RH
MON 202005 2500 UTC
010-040N / 090-141E
Prepared at 202005 251316



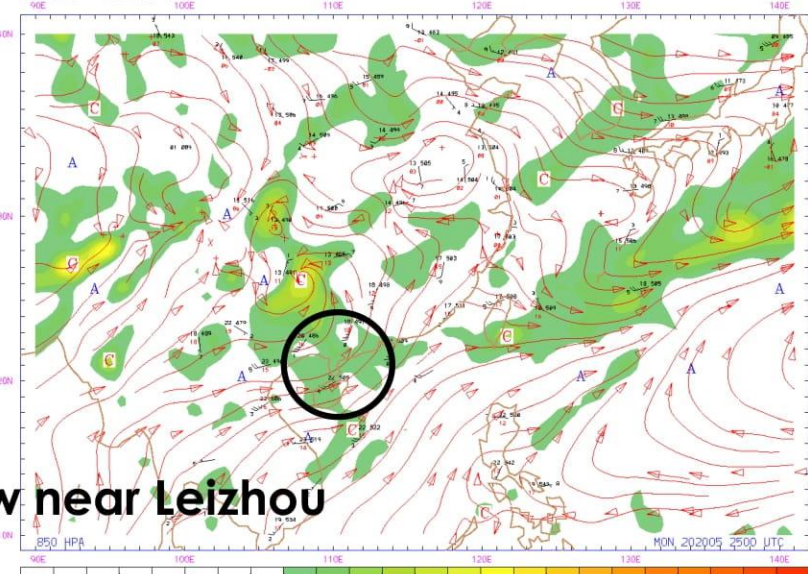
UPPER AIR 700 HPA
GTS obs + NHM SL & RH
MON 202005 2500 UTC
010-040N / 090-141E
Prepared at 202005 251316



UPPER AIR 925 HPA
GTS obs + NHM SL & RH
MON 202005 2500 UTC
010-040N / 090-141E
Prepared at 202005 251315



UPPER AIR 850 HPA
GTS obs + NHM SL & VT
MON 202005 2500 UTC
010-040N / 090-141E
Prepared at 202005 251317



香港 25 MAY 2020 00 UTC

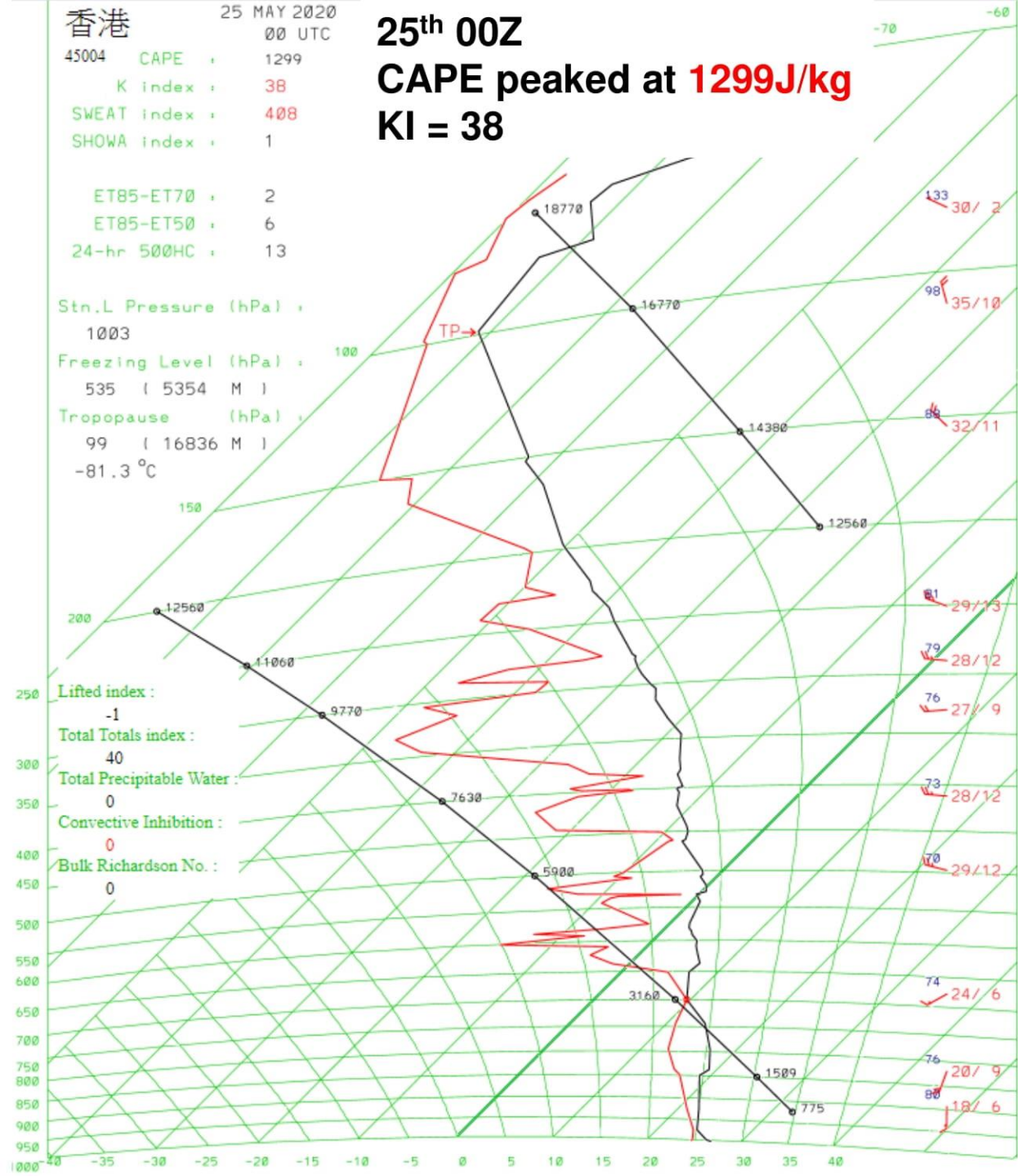
45004 CAPE : 1299
K index : 38
SWEAT index : 408
SHOWA index : 1

ET85-ET70 : 2
ET85-ET50 : 6
24-hr 500HC : 13

Stn.L Pressure (hPa) : 1003
Freezing Level (hPa) : 535 (5354 M)
Tropopause (hPa) : 99 (16836 M)
-81.3 °C

Lifted index : -1
Total Totals index : 40
Total Precipitable Water : 0
Convective Inhibition : 0
Bulk Richardson No. : 0

25th 00Z
CAPE peaked at 1299J/kg
KI = 38



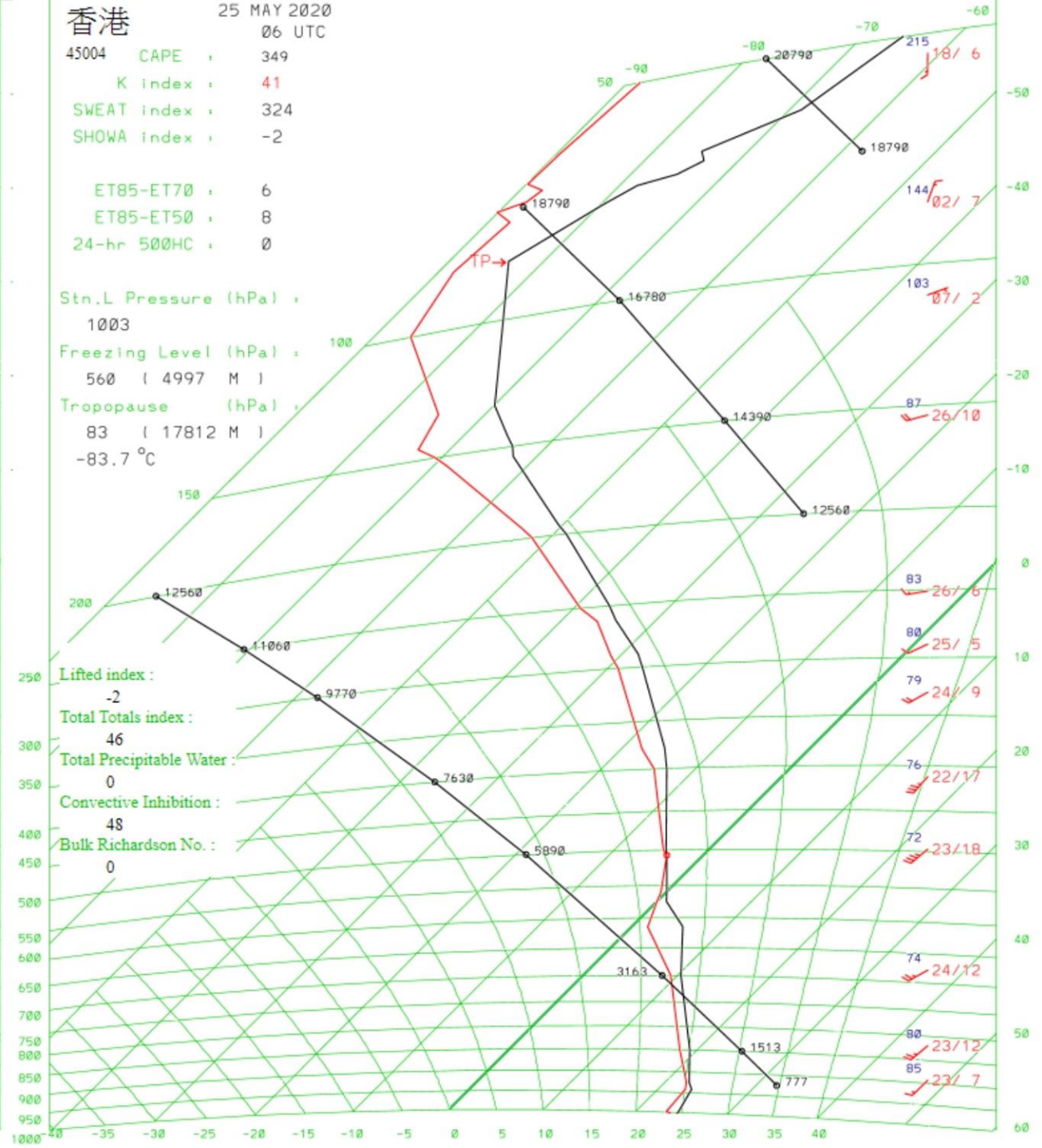
香港 25 MAY 2020 06 UTC

45004 CAPE : 349
K index : 41
SWEAT index : 324
SHOWA index : -2

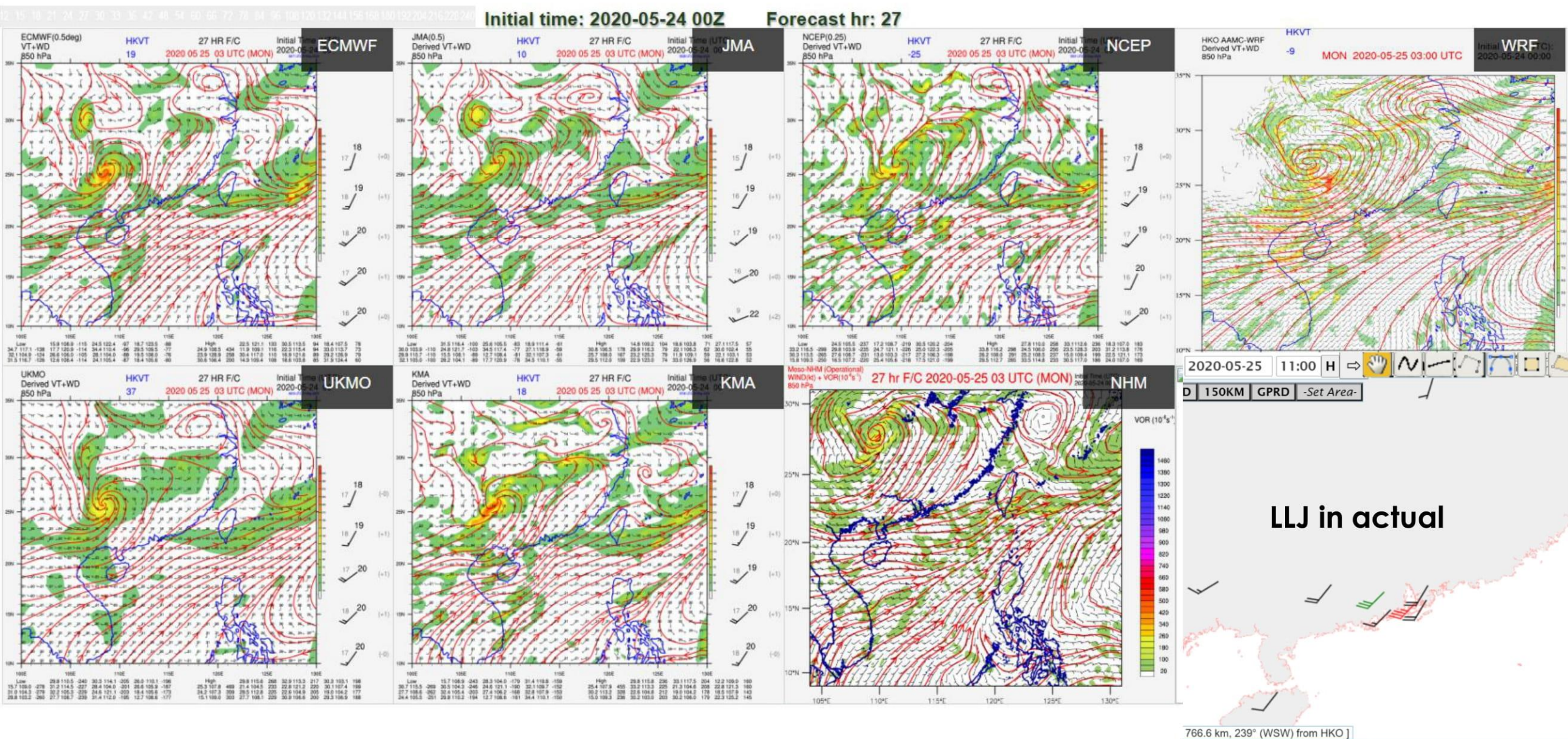
ET85-ET70 : 6
ET85-ET50 : 8
24-hr 500HC : 0

Stn.L Pressure (hPa) : 1003
Freezing Level (hPa) : 560 (4997 M)
Tropopause (hPa) : 83 (17812 M)
-83.7 °C

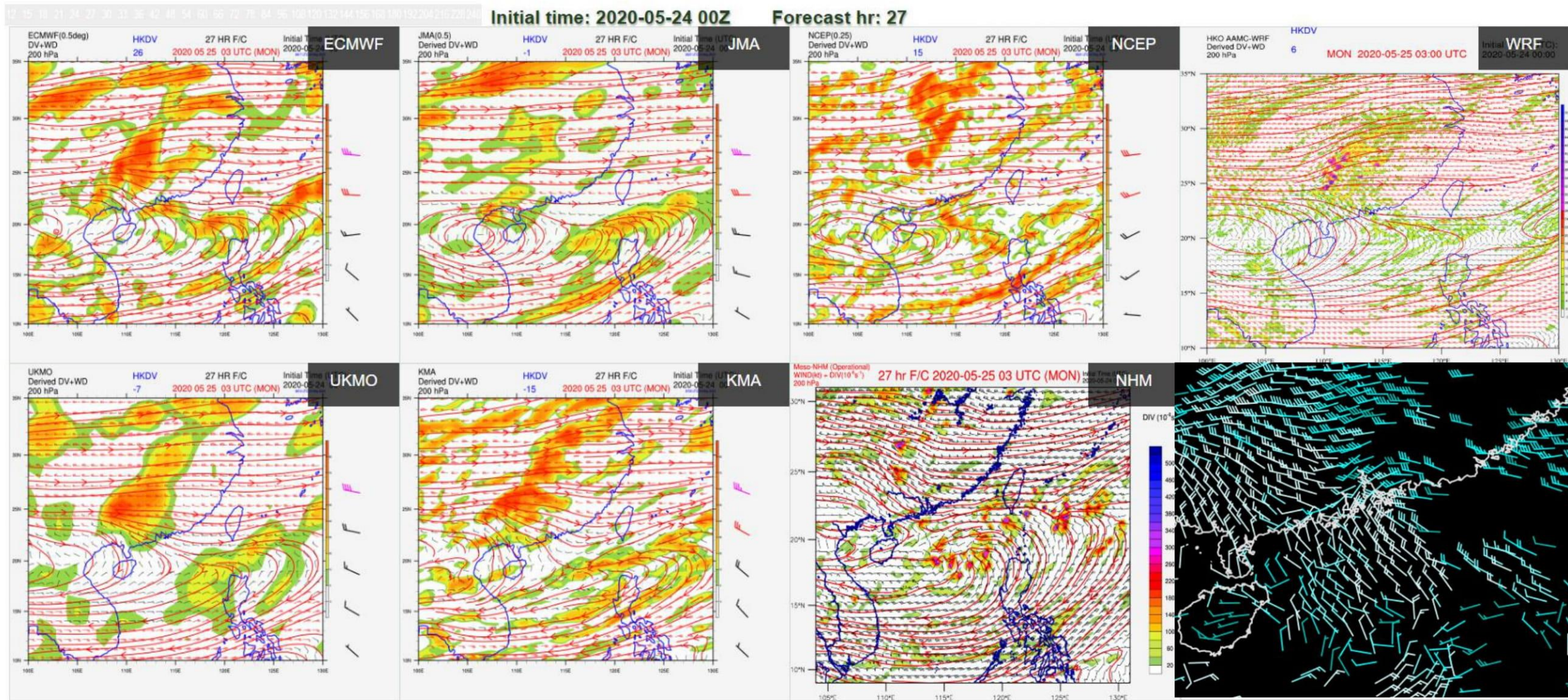
Lifted index : -2
Total Totals index : 46
Total Precipitable Water : 0
Convective Inhibition : 48
Bulk Richardson No. : 0



Models forecast much weaker winds on 850 hPa



Models: 200hPa divergence too **weak**, lack jets.



Actual divergence was **strong**, winds ~30kt.

Warm-season MCS, elevated thunderstorms and heavy rain (Moore et al. 2003):

<https://journals.ametsoc.org/doi/abs/10.1175/1520-0434%282003%29018%3C0861%3A%2EOWET%3E2.0.CO%3B2>

favorable factors for elevated significant convections and heavy rain:

- North-south **EPT gradient**
- S - SW'ly **LLJ**
- **Moisture convergence ridge** on 925 hPa (and/or 850 hPa)
- Max. of +ve advection of EPT
- Mid-tropospheric SW'ly flow

Warm-season MCS, elevated thunderstorms and heavy rain (Moore et al. 2003):

<https://journals.ametsoc.org/doi/abs/10.1175/1520-0434%282003%29018%3C0861%3A%2EOWET%3E2.0.CO%3B2>

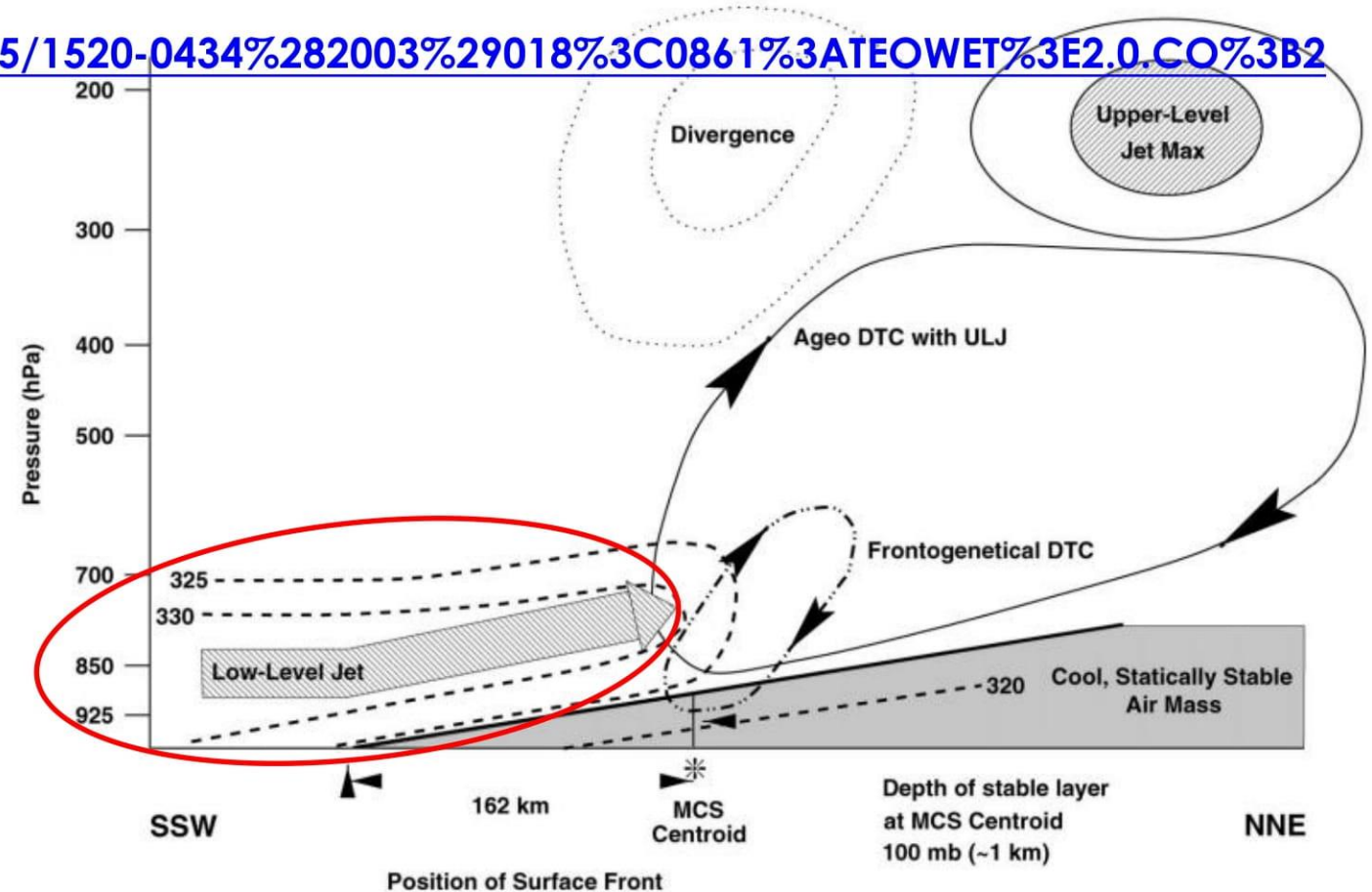


FIG. 14. Schematic cross-sectional view taken parallel to the LLJ across the frontal zone. Dashed lines represent typical θ_e values, the large stippled arrow represents the ascending LLJ, the thin dotted oval represents the ageostrophic direct thermal circulation associated with the upper-level jet streak, and the thick dashed oval represents the direct thermal circulation associated with the low-level frontogenetical forcing. The area aloft enclosed by dotted lines indicates upper-level divergence; the area aloft enclosed by solid lines denotes location of upper-level jet streak. Note that in this cross section the horizontal distance between the MCS and the location of the upper-level jet maximum is not to scale.

Moisture Flux Convergence (MFC)

- Ref: <https://journals.ametsoc.org/doi/pdf/10.1175/W>.

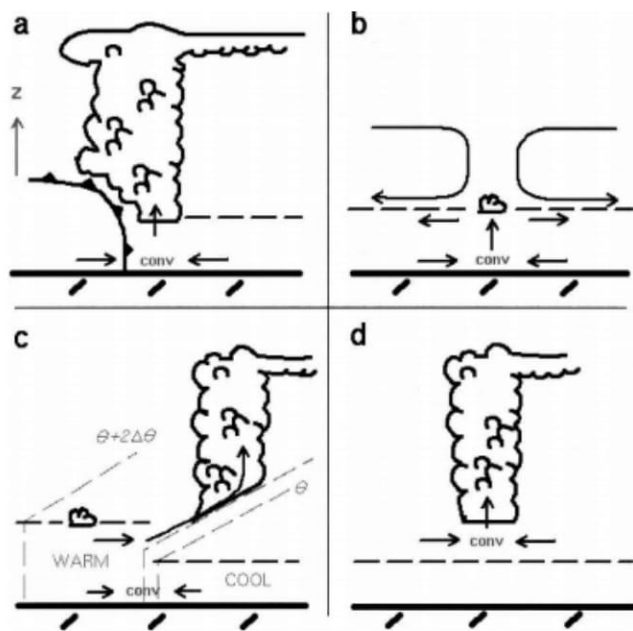


FIG. 2. Schematic of subcloud horizontal mass convergence (conv) as it relates to cumulus convection (represented by cloud outline). Arrows represent streamlines. Thick dashed line indicates top of PBL. (a) Surface horizontal mass convergence maximum is associated with a deep tropospheric circulation and deep moist convection. (b) Surface horizontal mass convergence maximum is associated with shallow cumulus development owing to midlevel subsidence and/or a capping inversion. (c) Surface horizontal mass convergence maximum is located near change in boundary layer depth. Thin dashed line indicates isentropic surfaces. (d) Horizontal mass convergence maximum is rooted above the local boundary layer.

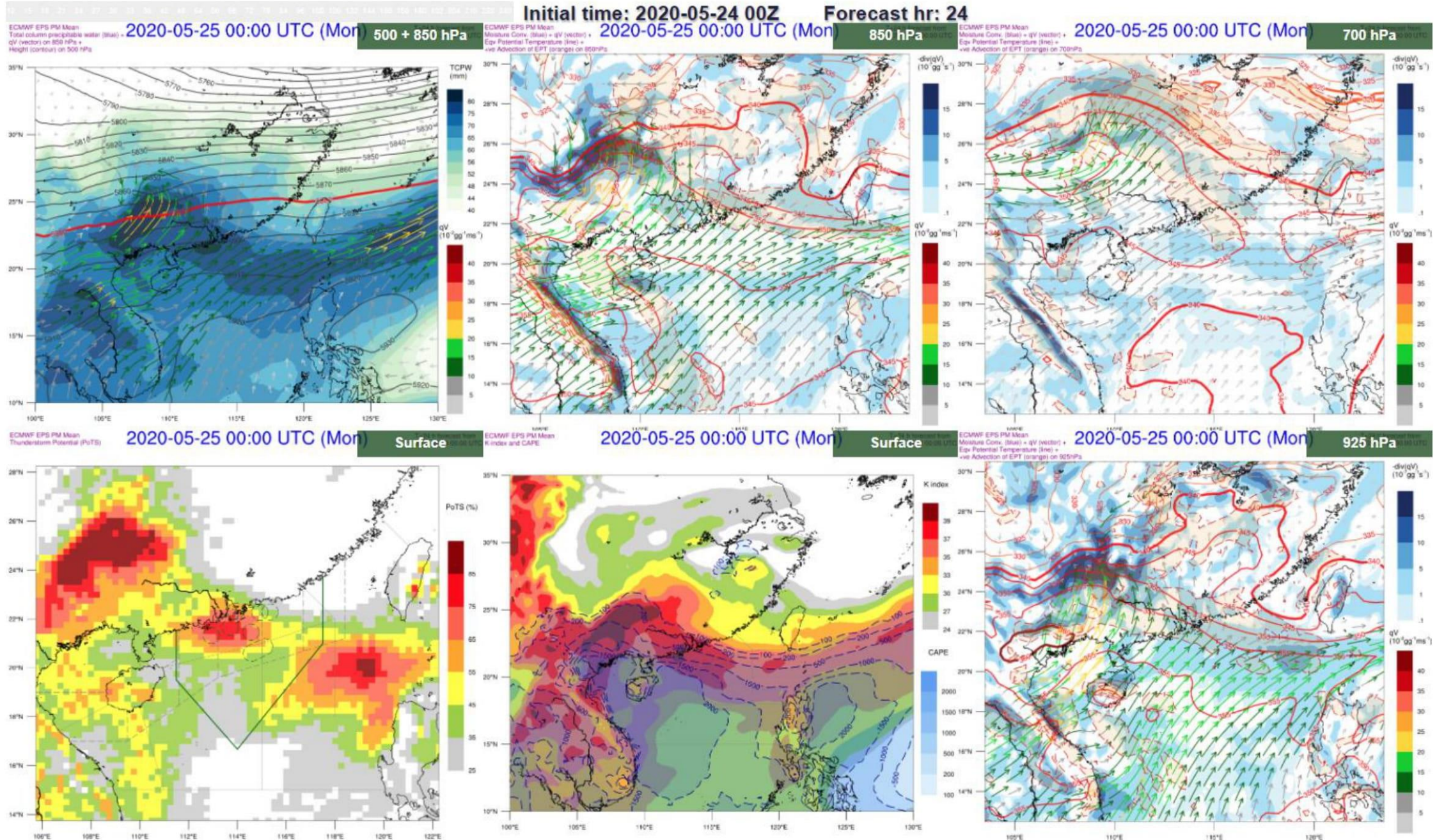
$$\frac{\partial q}{\partial t} + u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y} + \omega \frac{\partial q}{\partial p} + q \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} \right) = E - P. \quad (2)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x} (qu) + \frac{\partial}{\partial y} (qv) + \frac{\partial}{\partial p} (q\omega) = E - P.$$

$$\underbrace{\frac{\partial q}{\partial t}}_{\text{local rate of change of } q} + \underbrace{\nabla \cdot (q\mathbf{V}_h)}_{\text{-horizontal MFC}} + \underbrace{\frac{\partial}{\partial p} (q\omega)}_{\text{-vertical MFC}} = \underbrace{E - P}_{\text{sources and sinks}}, \quad (3)$$

Precipitation production is proportional to the vertical integrated product of specific humidity with horizontal mass convergence:

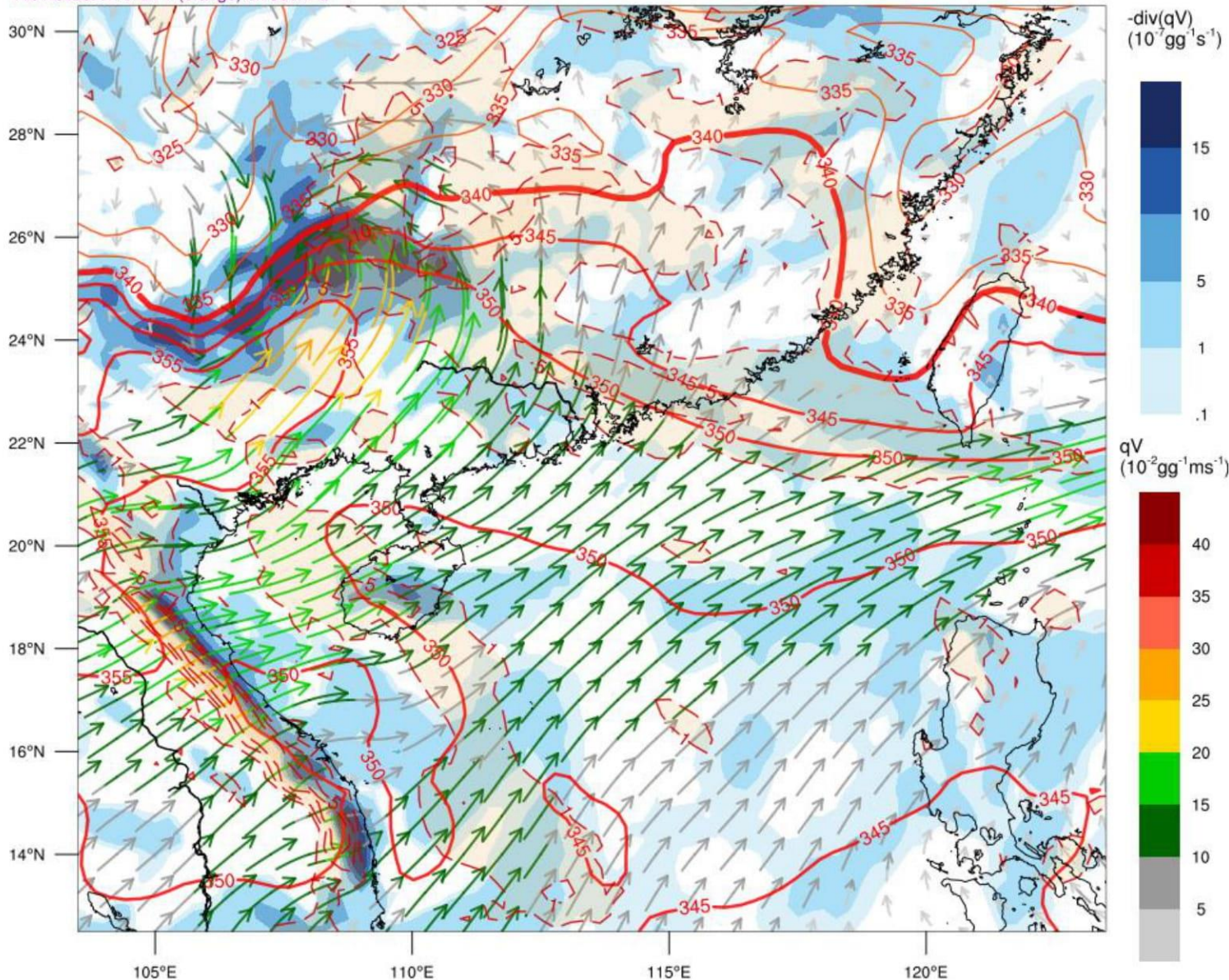
$$\bar{P} \approx -\frac{1}{g} \int_0^{P_s} q \nabla \cdot \mathbf{V}_h dp. \quad (7)$$



ECMWF EPS PM Mean
Moisture Conv. (blue) + qV (vector) +
Eqv Potential Temperature (line) +
+ve Advection of EPT (orange) on 850hPa

2020-05-25 00:00 UTC (Mon)

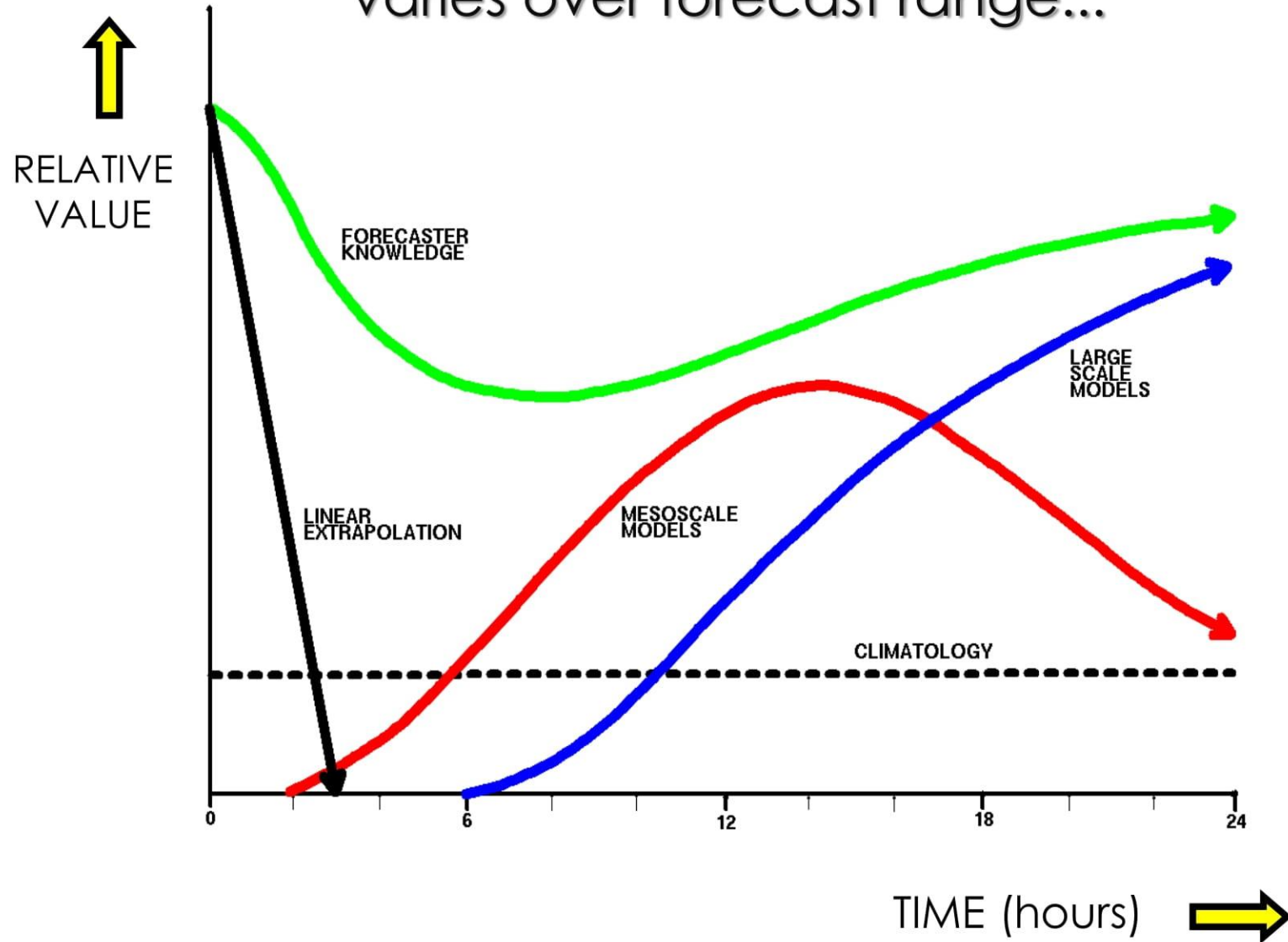
T+24 h forecast from
2020-05-24 00:00 UTC



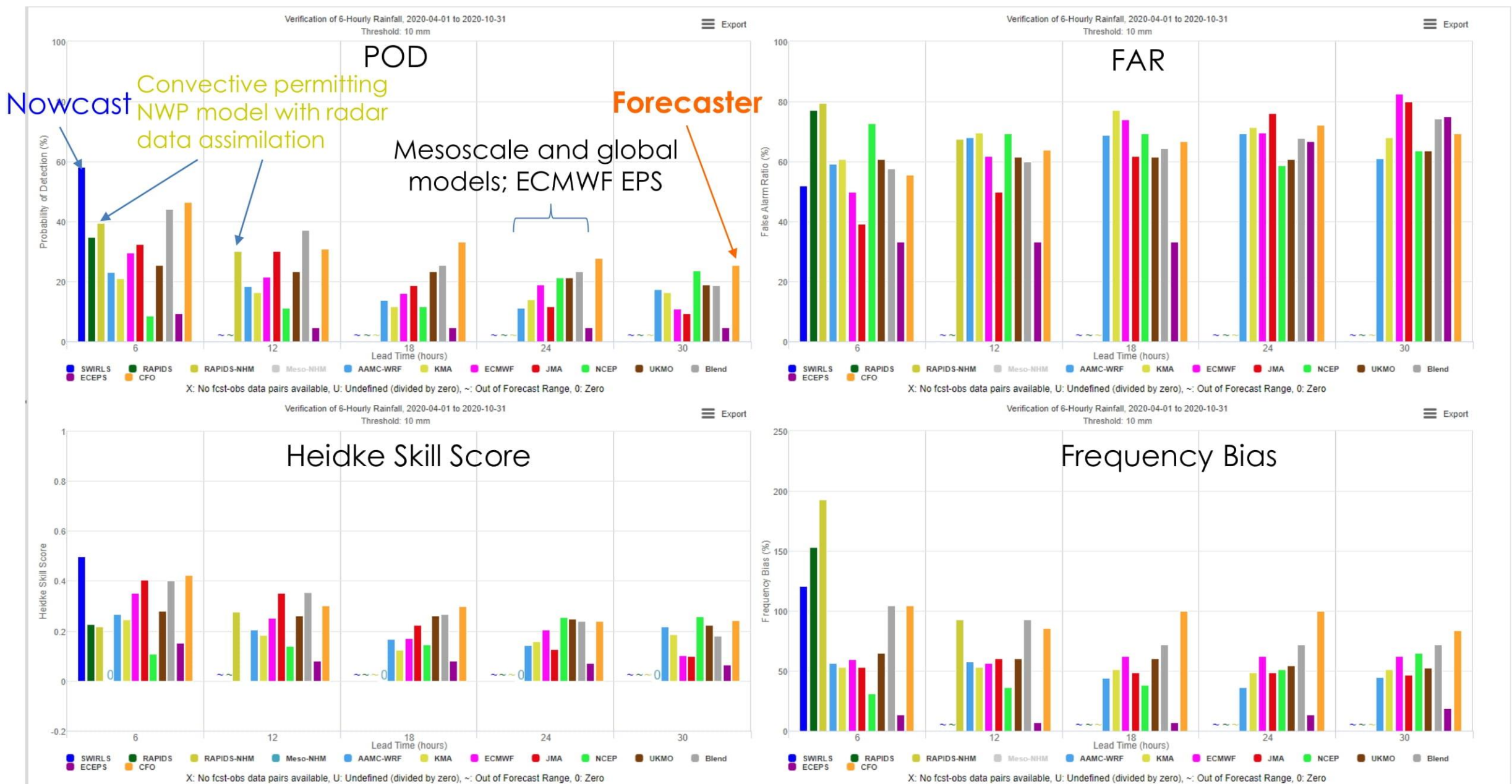
Moisture Conv. (blue) + qV (vector) +
Eqv Potential Temperature (line) +
+ve Advection of EPT (orange) on 850

Hint of favourable
significant convection
developments from
diagnostics

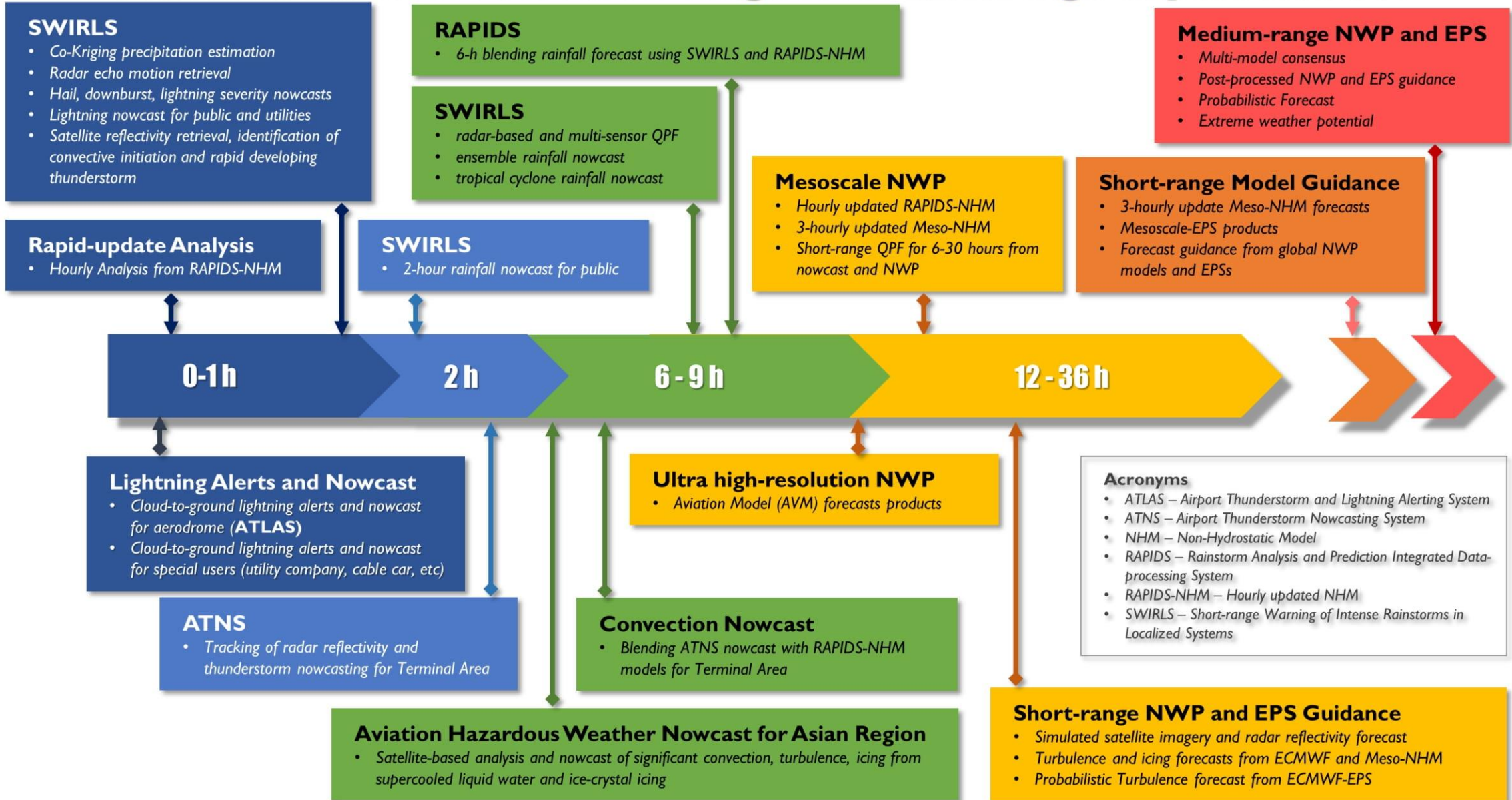
Relative value of different methods used to determine trend varies over forecast range...



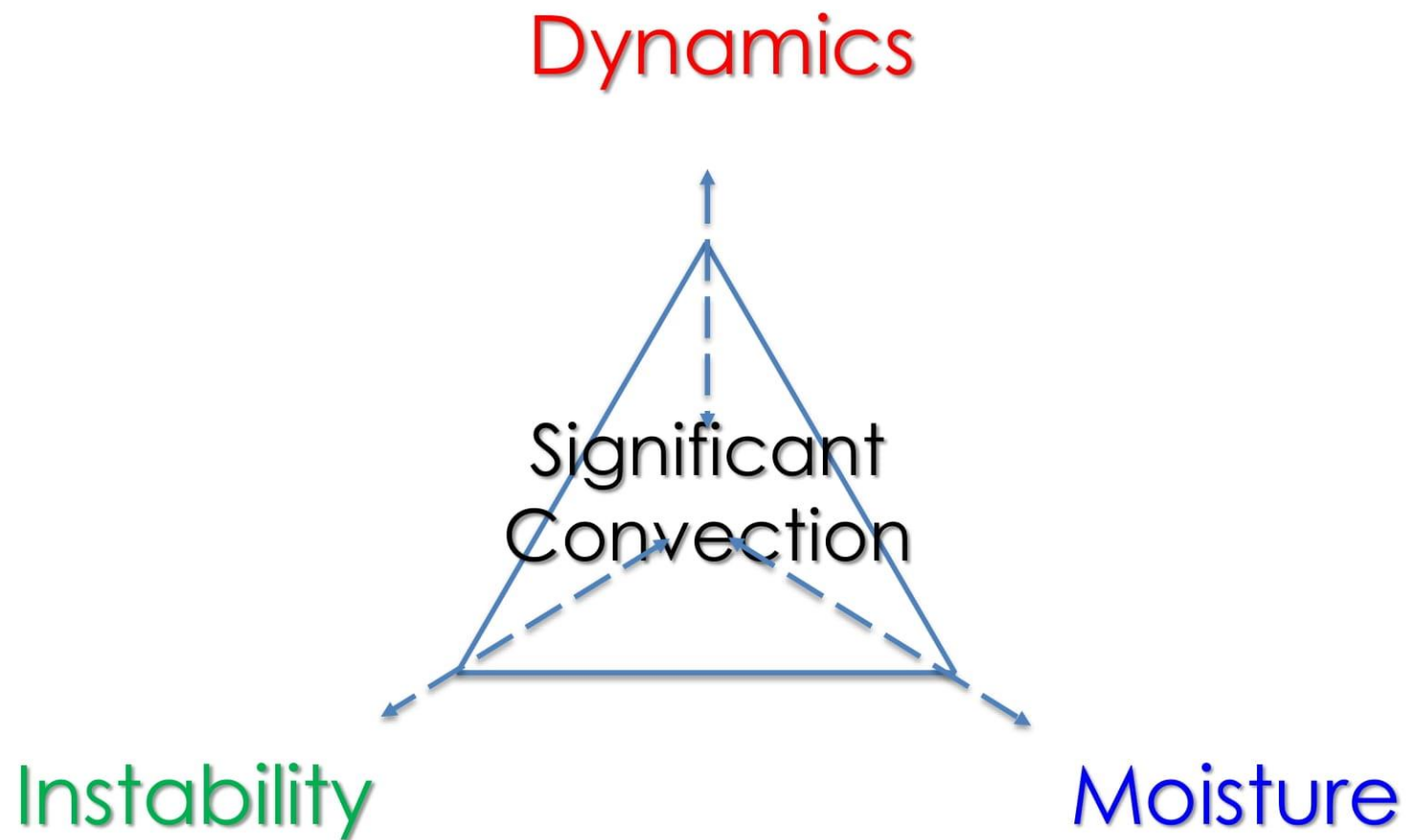
Verification of 6 h accumulated rainfall up to T+30h (Apr - Oct 2020; Threshold 10 mm)



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

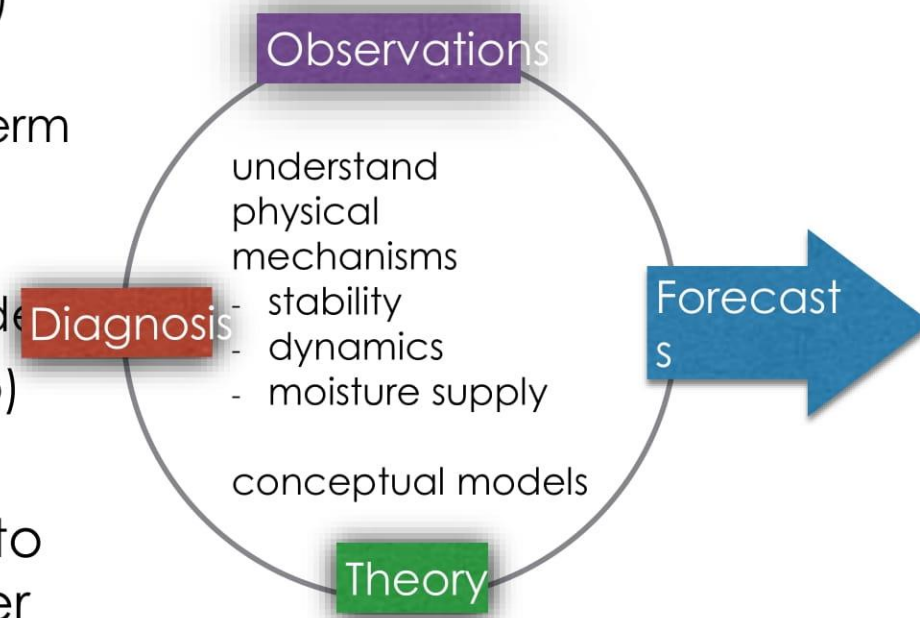


Perspectives of predicting high-impact convective weather processes



Rule of thumbs in severe weather forecasting

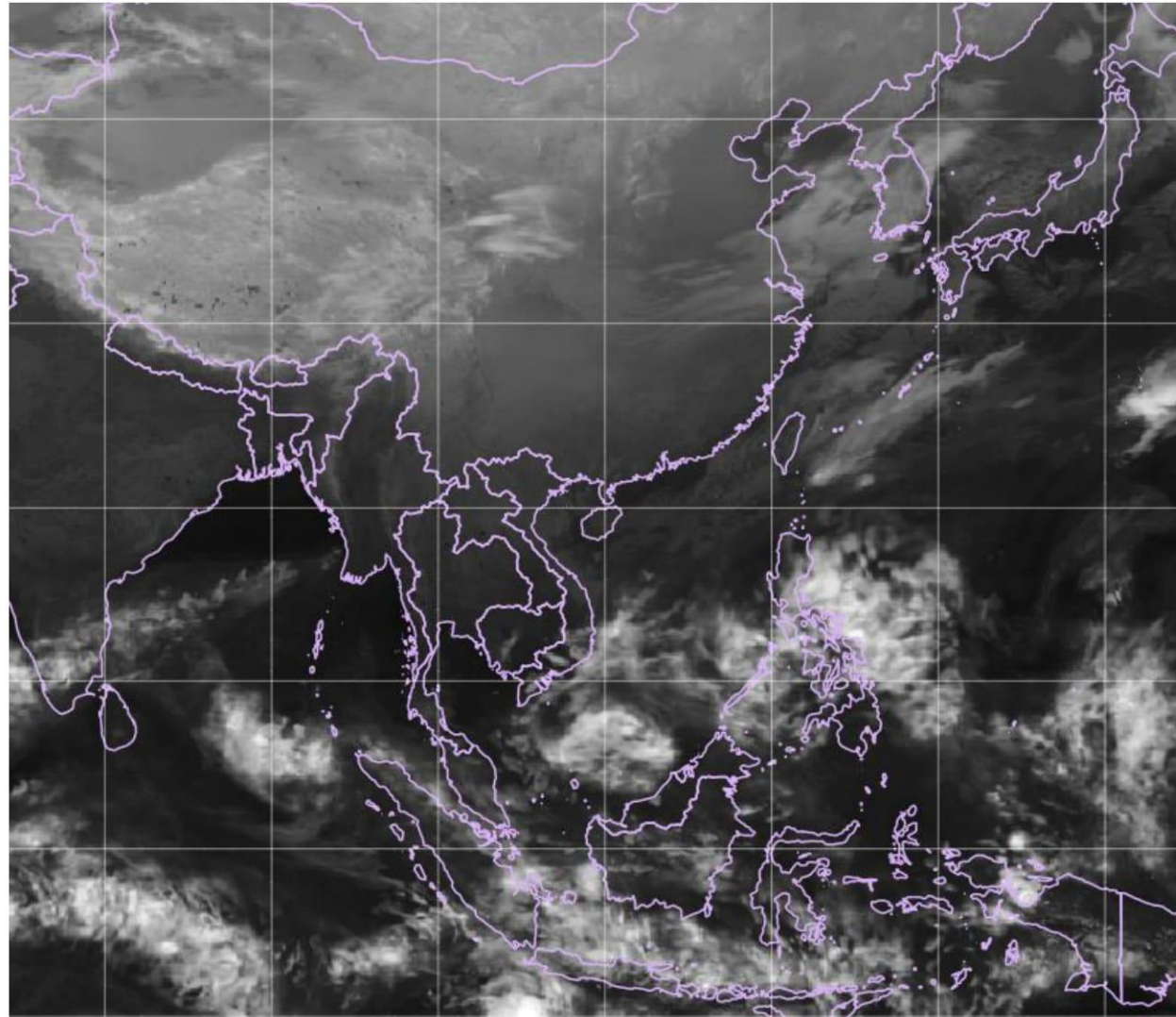
- **Understanding** of physical mechanisms about initiation movement and development
 - interpretation of radar sequence (local to regional mosaic) and satellite products
 - deduce possible supporting factors from analysis or short-term forecast products from NWP model on dynamical and thermodynamics factors
 - model QPF are results from many processes in NWP model
 - jumpiness issues (→ EPS consensus diagnostics may help)
- **Diagnosis** of model analysis/forecasts and connecting to conceptual models of heavy rain or mesoscale weather processes
- **Verification** - subjective and objective metrics assist in understanding accuracy, confidence and jumpiness of model forecasts



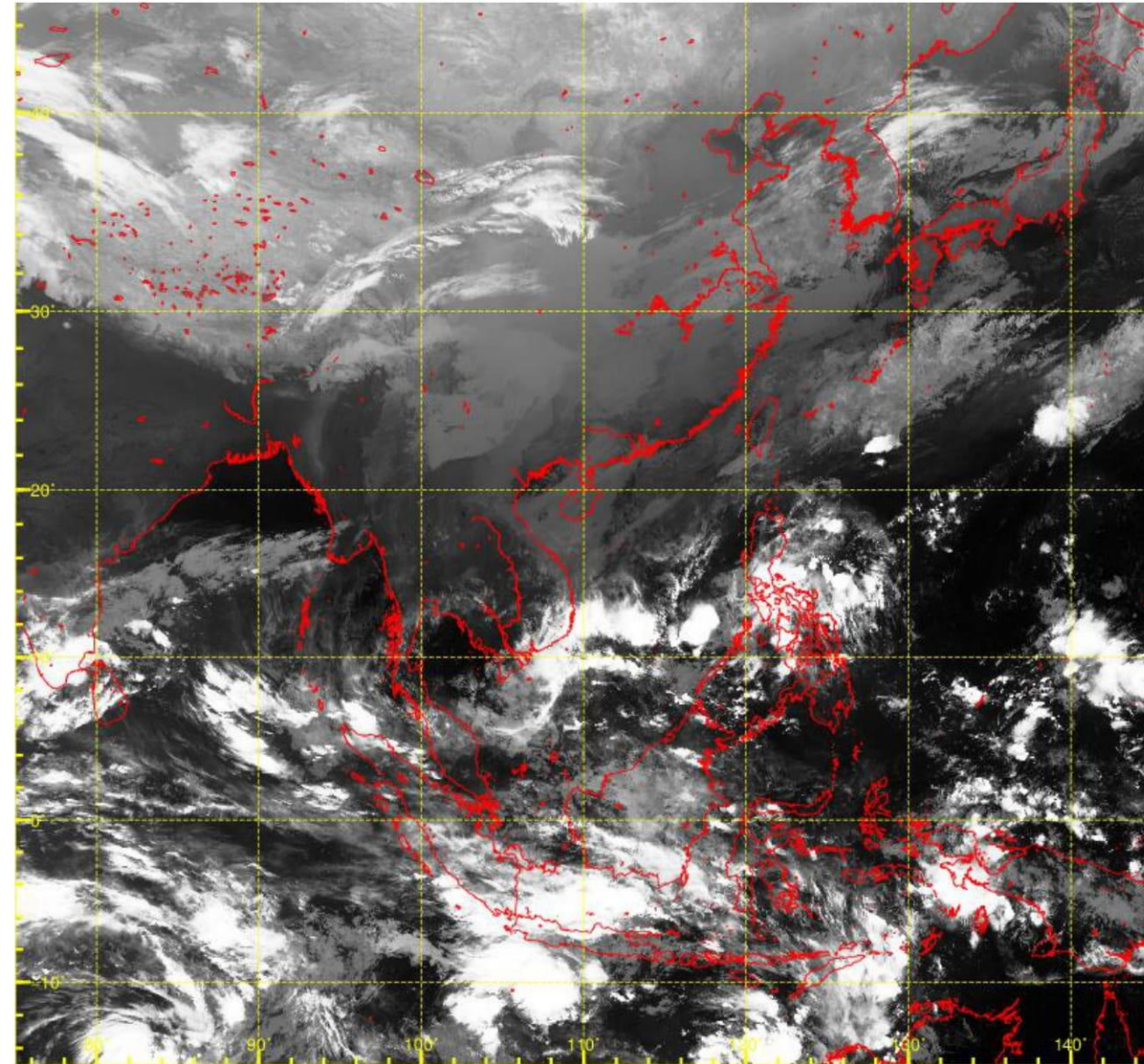
Simulated satellite imagery from NWP models

ECMWF HRES

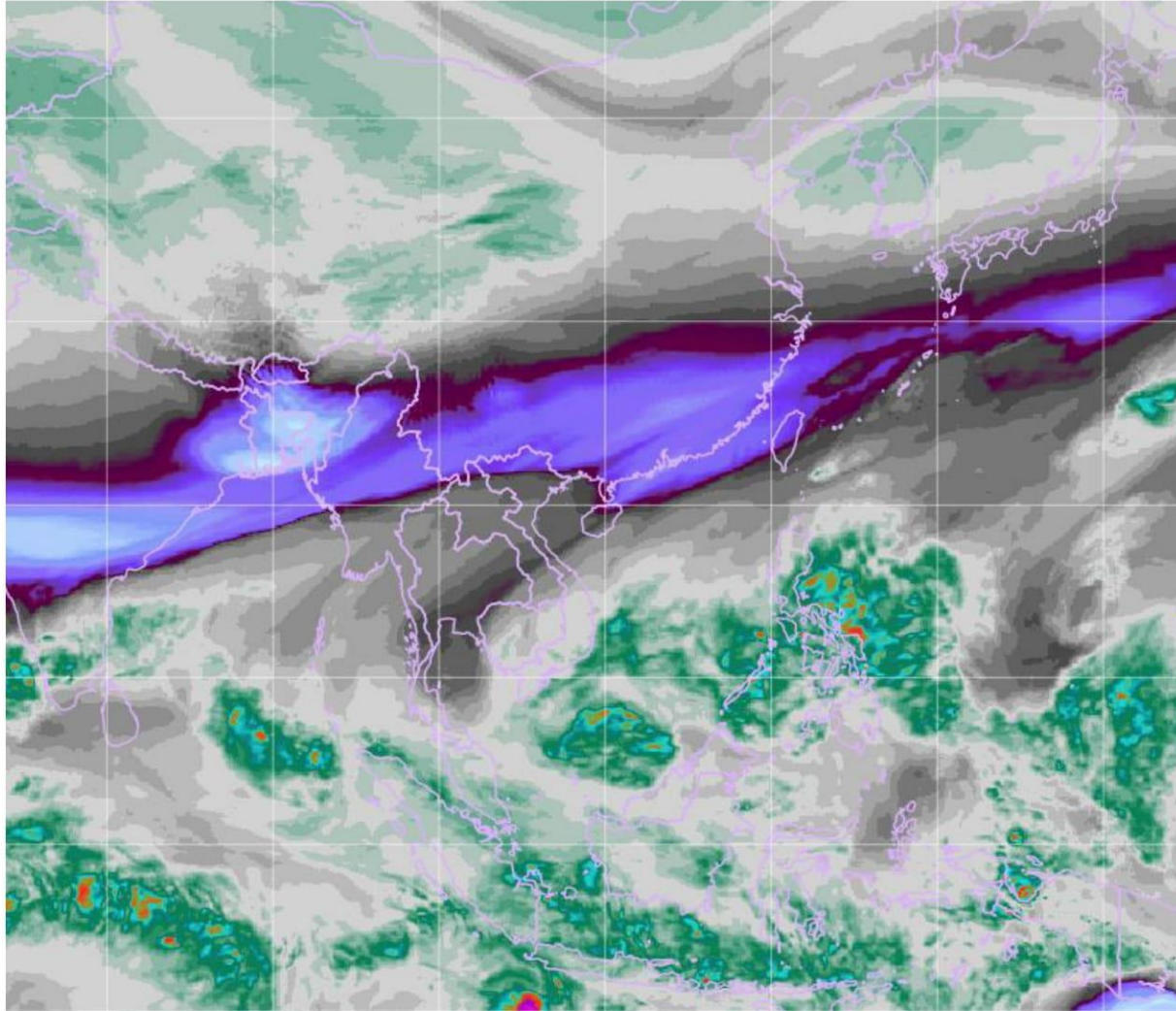
T+36h Forecast from 2020-12-07 12:00 UTC



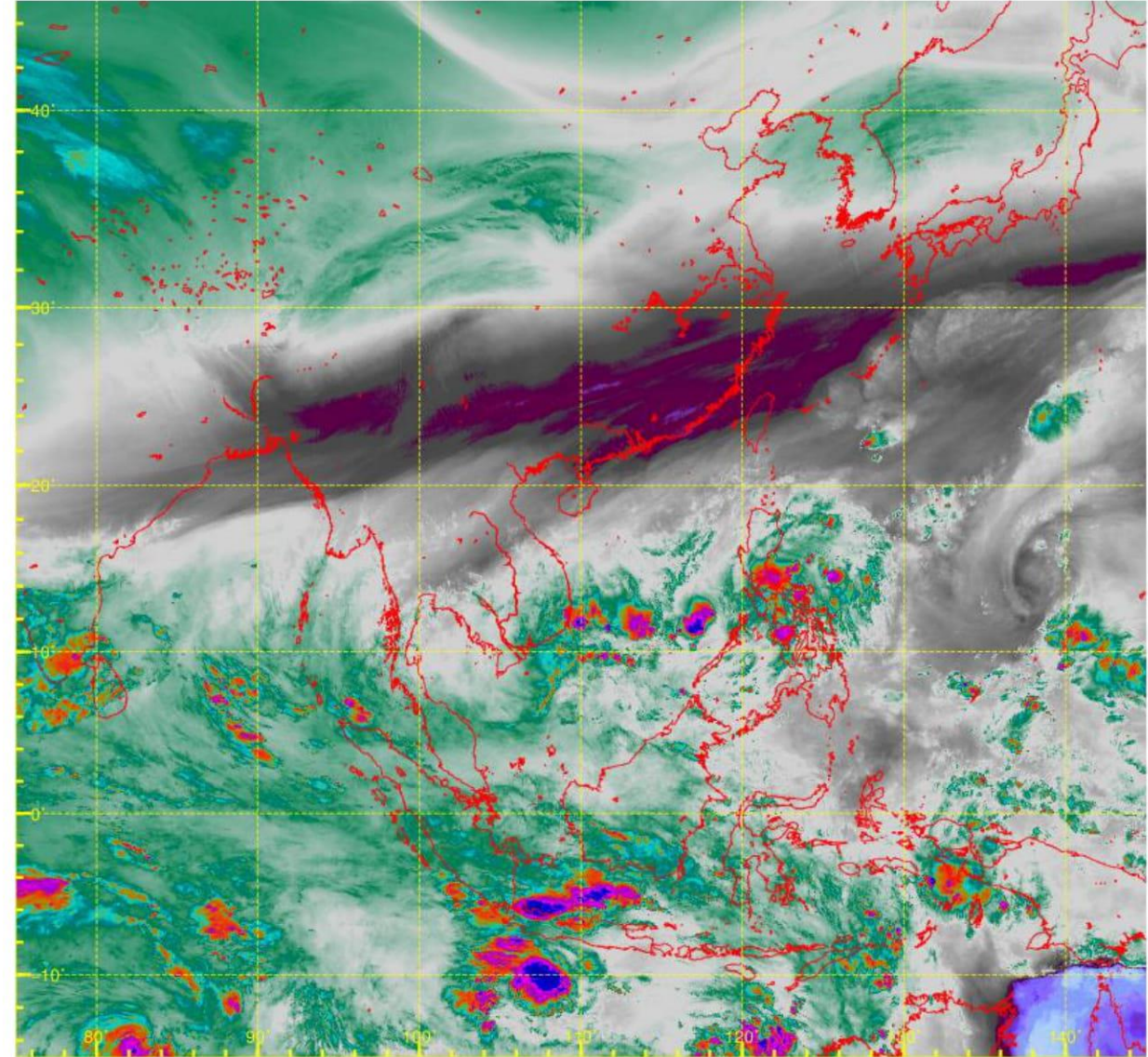
2020-12-07 00:00 UTC



ECMWF HRES
T+36h Forecast from 2020-12-07 12:00 UTC

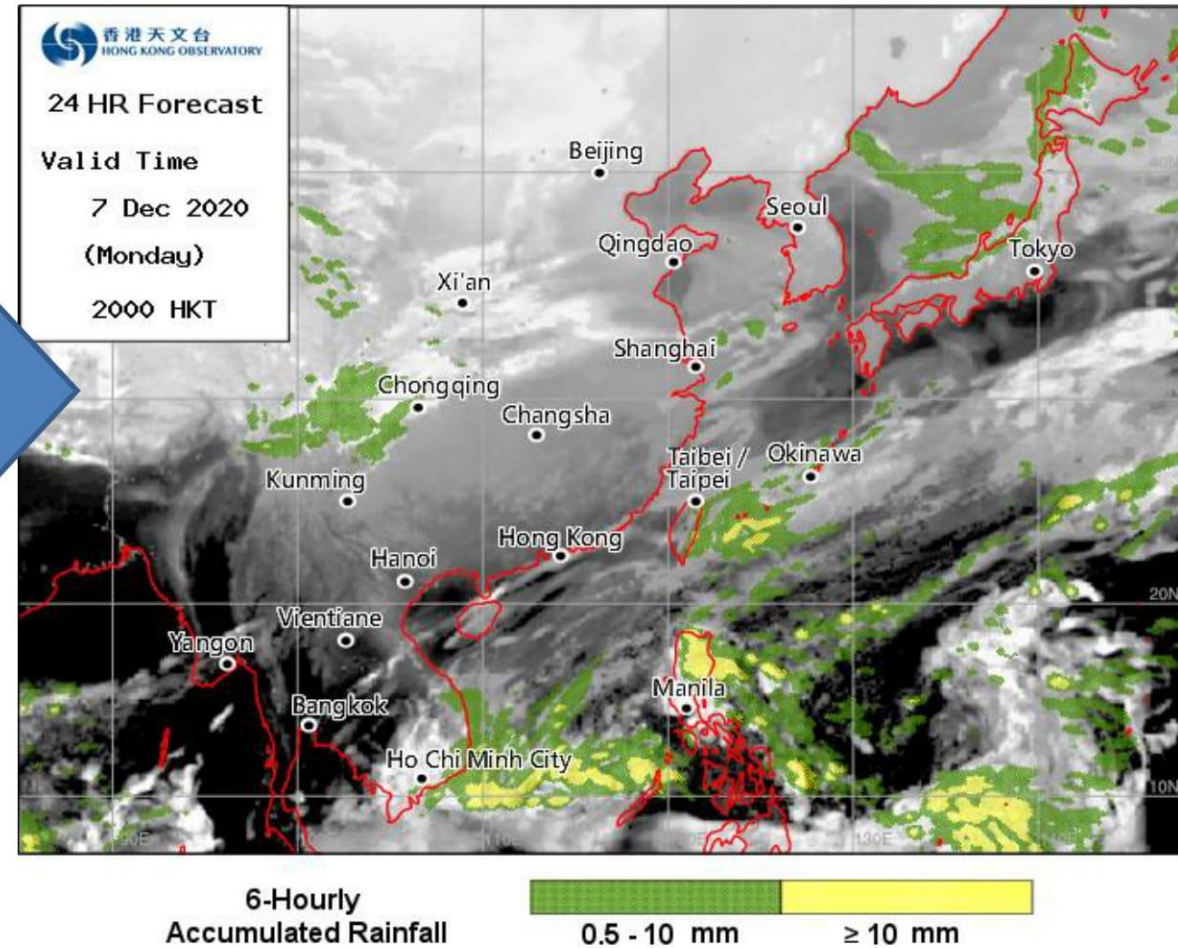


2020-12-07 00:00 UTC



Why NWP simulated satellite imagery ?

- Simulated imagery can be used for interpreting NWP model output and presenting it as if it were a satellite image
- Useful for presenting NWP outputs general users as “future” cloud images
- Verification of model
- As “observations” in data assimilation process



Reference:

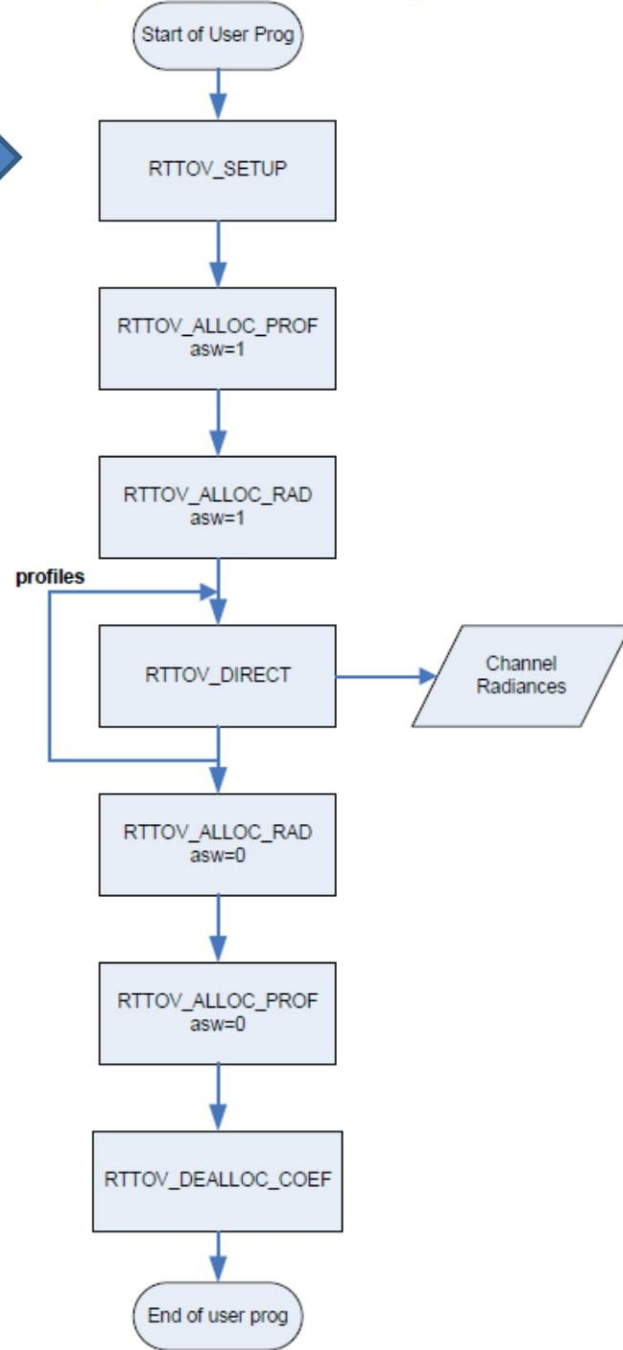
<https://nwp-saf.eumetsat.int/site/featured-articles/simulating-satellite-imagery-verify-nwp-models-f...>

What you need to generate simulated satellite imagery ?

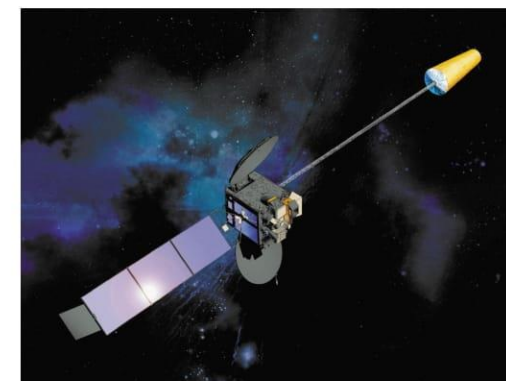
- Model profiles of temperature, humidity, pressure, cloud liquid water, cloud ice water, cloud fraction
 - Surface characteristics e.g. orography , land/sea mask, surface types (Earth's emissivity)
- Radiative Transfer Model
 - RTTOV
 - CRTM
 - SDSU

5.1 User calling tree for user program calling RTTOV

Vertical profile
from NWP model
forecast



Simulated
satellite
radiance



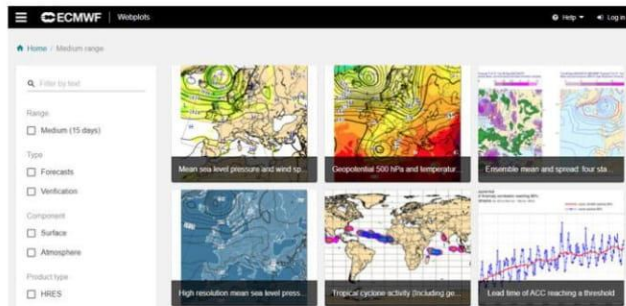
“Observed” radiance

ECMWF moves towards a policy of open data

7 October 2020



- News
- In focus
- Science blog
- Key facts and figures
- Media resources
- Videos



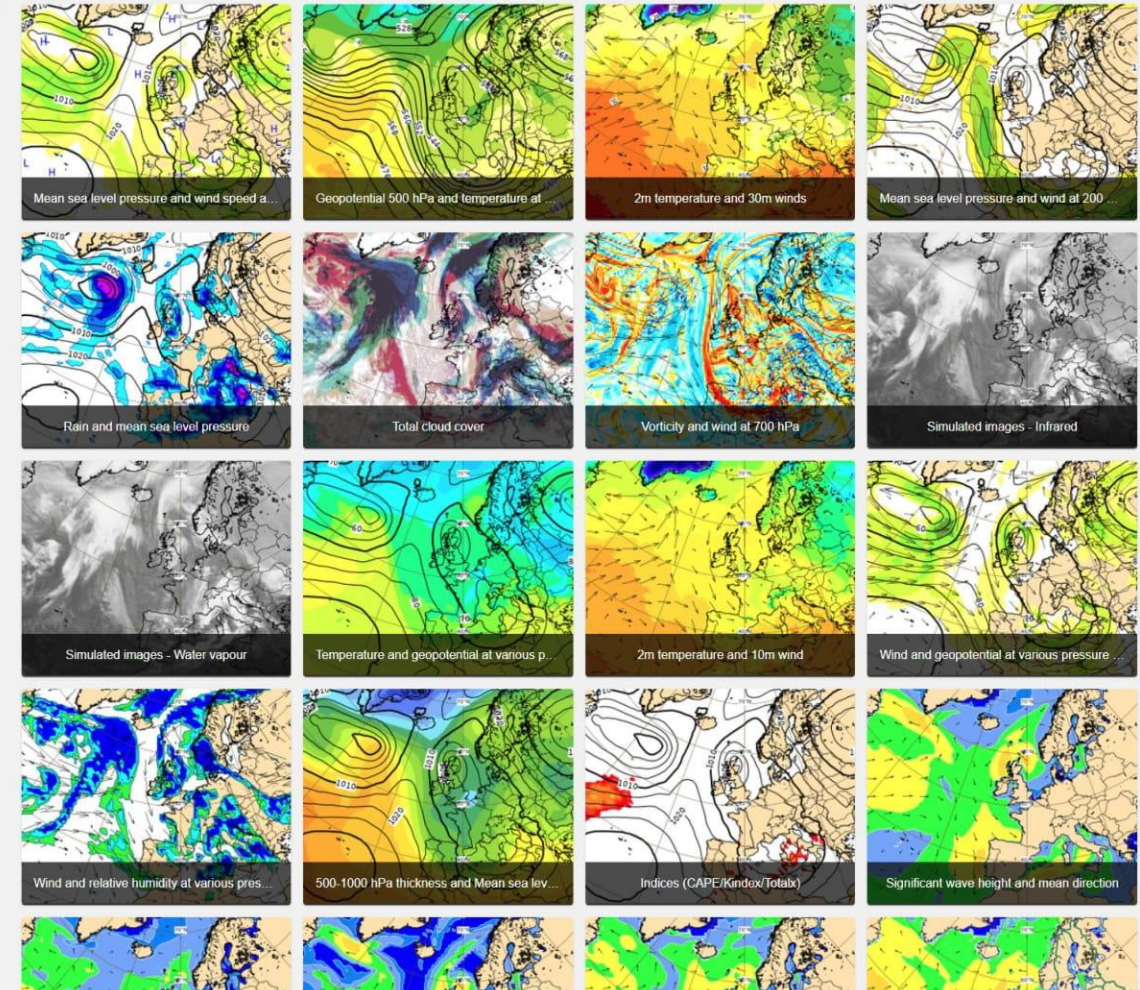
Forecast charts cover all regions of the world; the figure shows just a selection of the hundreds that are being made available.

From today (7 October 2020), hundreds of ECMWF forecast charts will become free and accessible to all.

Medium-range, extended-range and long-range forecast charts of temperature, wind, precipitation, clouds and ocean waves are just some of the products that are becoming available. With ECMWF's focus on ensemble prediction, charts also cover probability-based information, which provides a guide to forecast confidence. The likelihood of extreme conditions, as well as tropical and extratropical cyclone activity, are also included.

Home / Charts catalogue

- Search products
- Range
- Medium (15 days)
 - Extended (42 days)
 - Long (Months)
- Type
- Forecasts
 - Verification
- Component
- Surface
 - Atmosphere
- Product type
- High resolution forecast (HRES)
 - Ensemble forecast (ENS)
 - Combined (ENS + HRES)
 - Extreme forecast index
- Parameters
- Wind
 - Mean sea level pressure
 - Temperature
 - Geopotential
 - Precipitation
 - Cloud
 - Water vapour
 - Indices
 - Ocean waves
 - Surface characteristics
 - Snow
 - Tropical cyclones



ECMWF Search site...

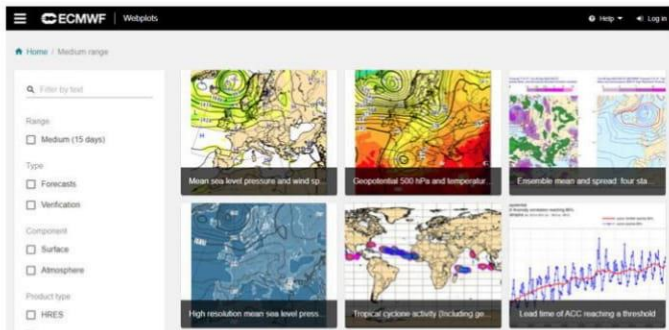
Home | About | Forecasts | Computing | Research | Learning

Who we are | What we do | Jobs | **Media centre** | Suppliers | Contact

ECMWF moves towards a policy of open data

7 October 2020

Share



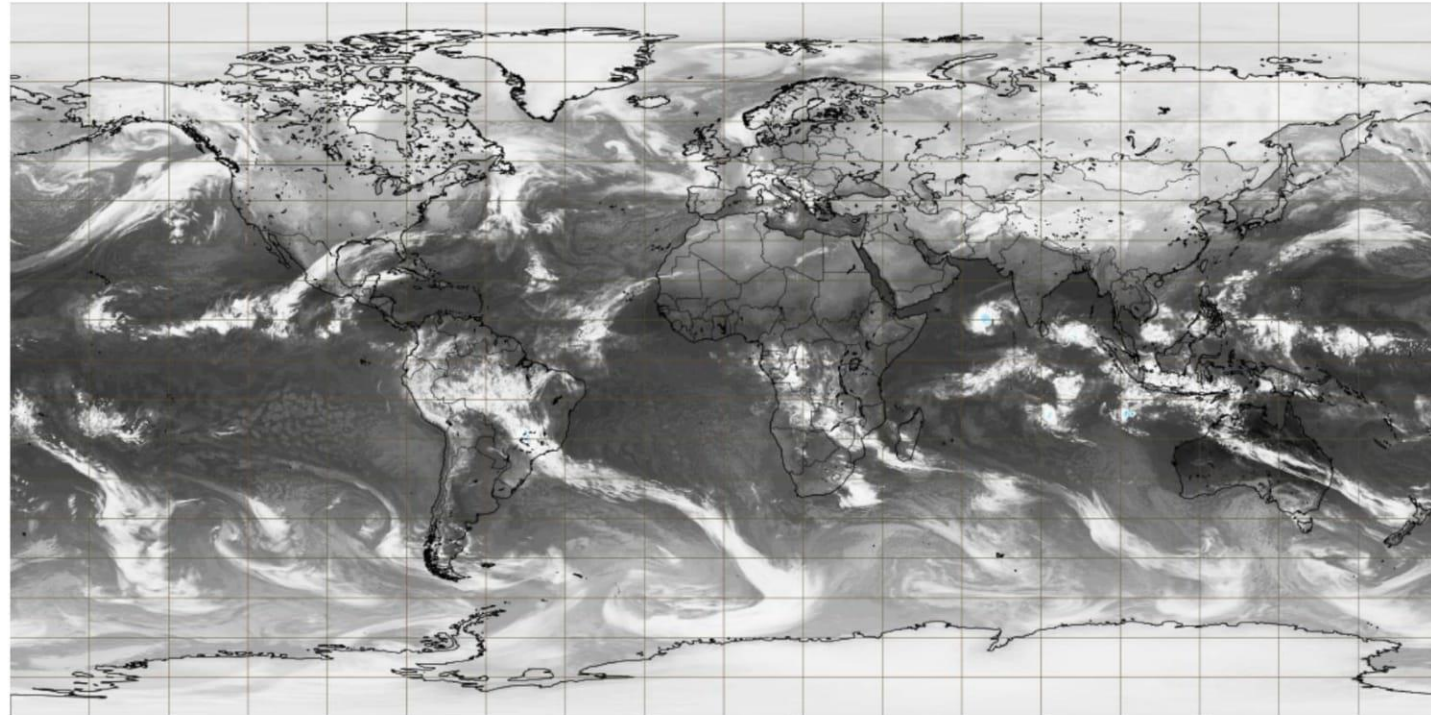
Forecast charts cover all regions of the world; the figure shows just a selection of the hundreds that are being made available.

From today (7 October 2020), hundreds of ECMWF forecast charts will become free and accessible to all.

Medium-range, extended-range and long-range forecast charts of temperature, wind, precipitation, clouds and ocean waves are just some of the products that are becoming available. With ECMWF's focus on ensemble prediction, charts also cover probability-based information, which provides a guide to forecast confidence. The likelihood of extreme conditions, as well as tropical and extratropical cyclone activity, are also included.

Simulated images - Infrared

Base time: Wed 02 Dec 2020 00 UTC, Valid time: Mon 07 Dec 2020 00 UTC, - T+120 h, Area : Global

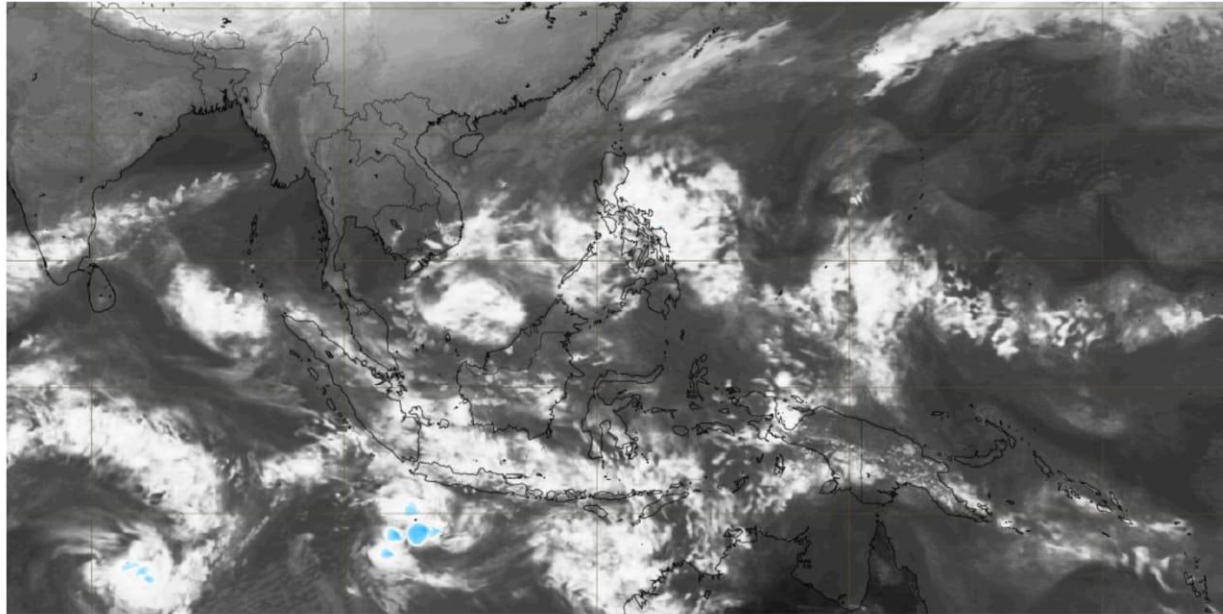


Simulated image: Infrared (IR) channel (C)



Simulated images - Infrared

Base time: Sat 05 Dec 2020 12 UTC, Valid time: Mon 07 Dec 2020 00 UTC, - T+36 h, Area : South East Asia & Indonesia

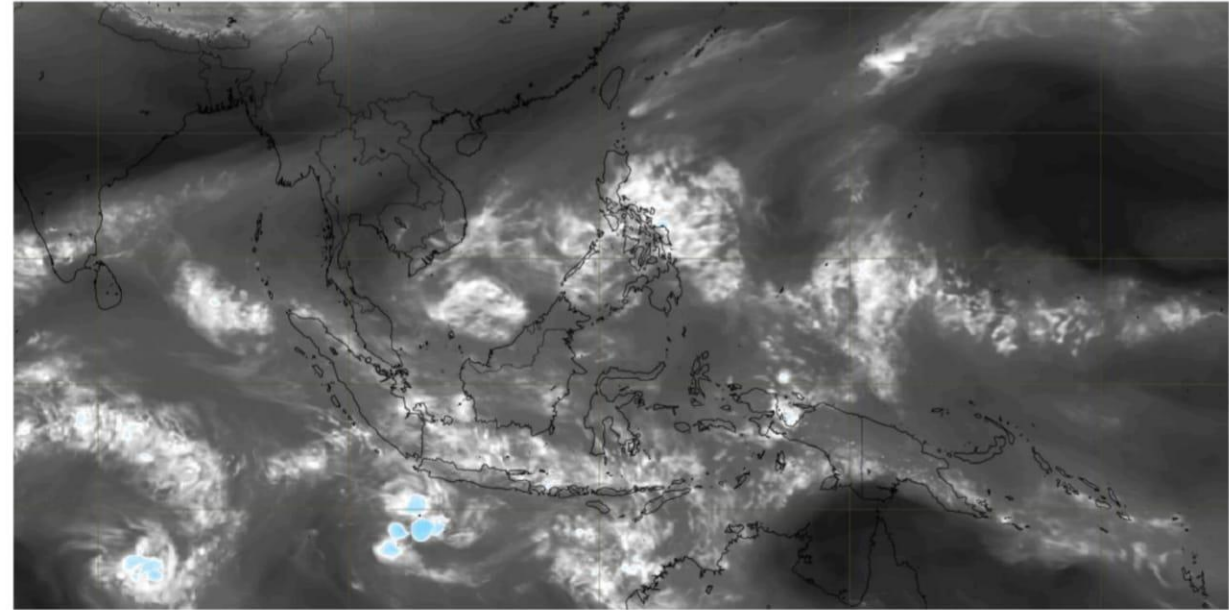


Simulated image: Infrared (IR) channel (C)



Simulated images - Water vapour

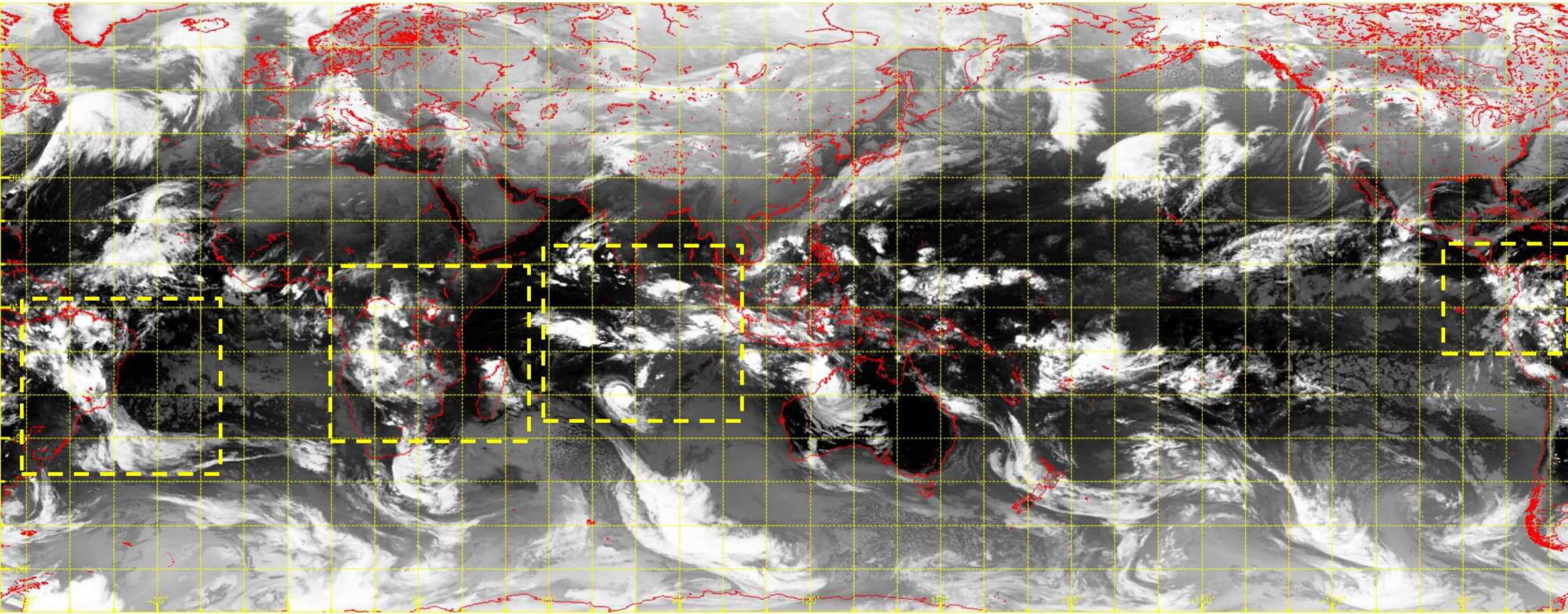
Base time: Sat 05 Dec 2020 12 UTC, Valid time: Mon 07 Dec 2020 00 UTC, - T+36 h, Area : South East Asia & Indonesia, Channel : Water vapour (~500hPa)



Simulated image: Water vapour (WV) ~500 hPa (C)

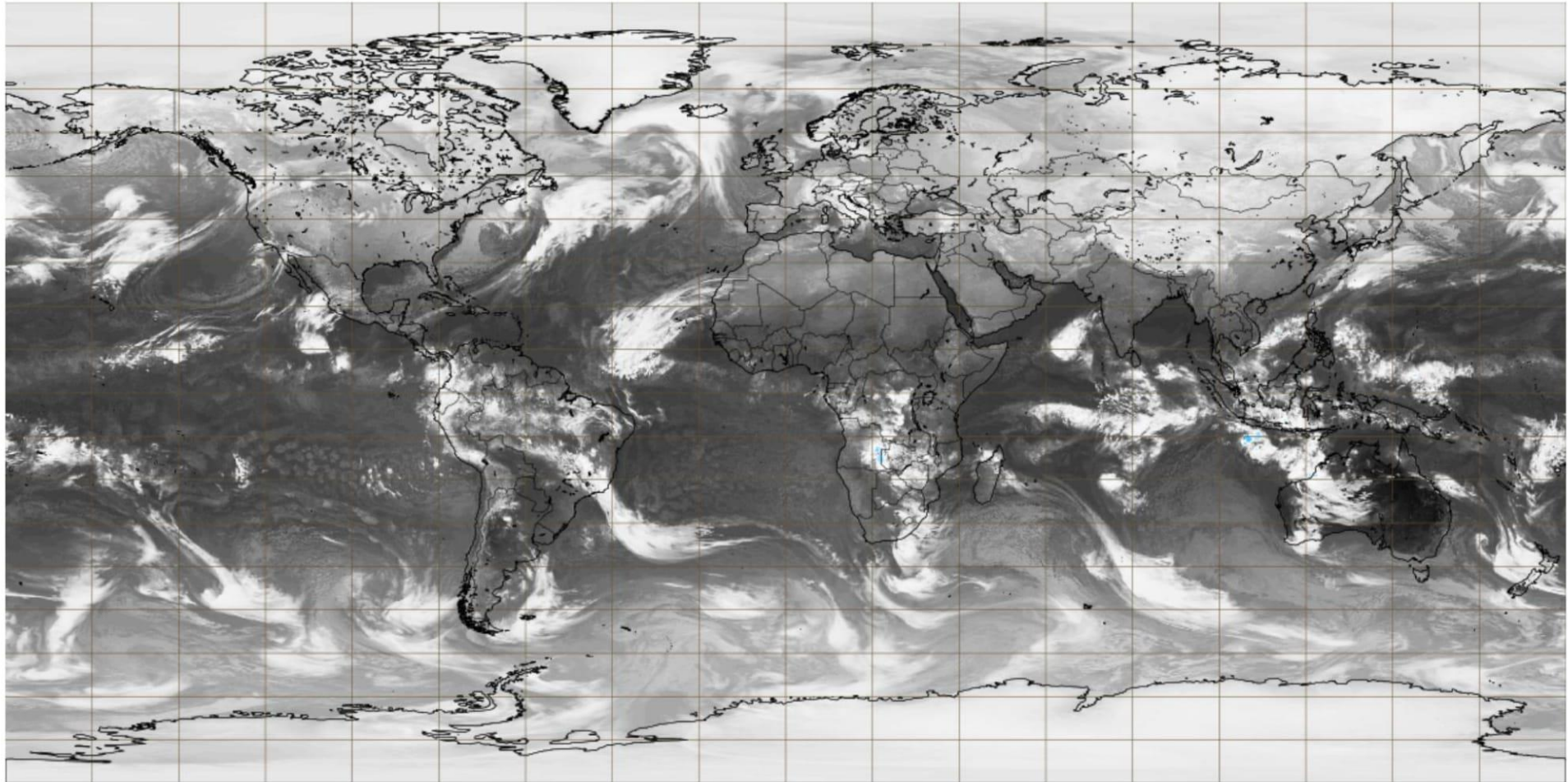


2020-12-09 00 UTC



Simulated images - Infrared

Base time: Fri 04 Dec 2020 12 UTC, Valid time: Wed 09 Dec 2020 00 UTC, - T+108 h, Area : Global



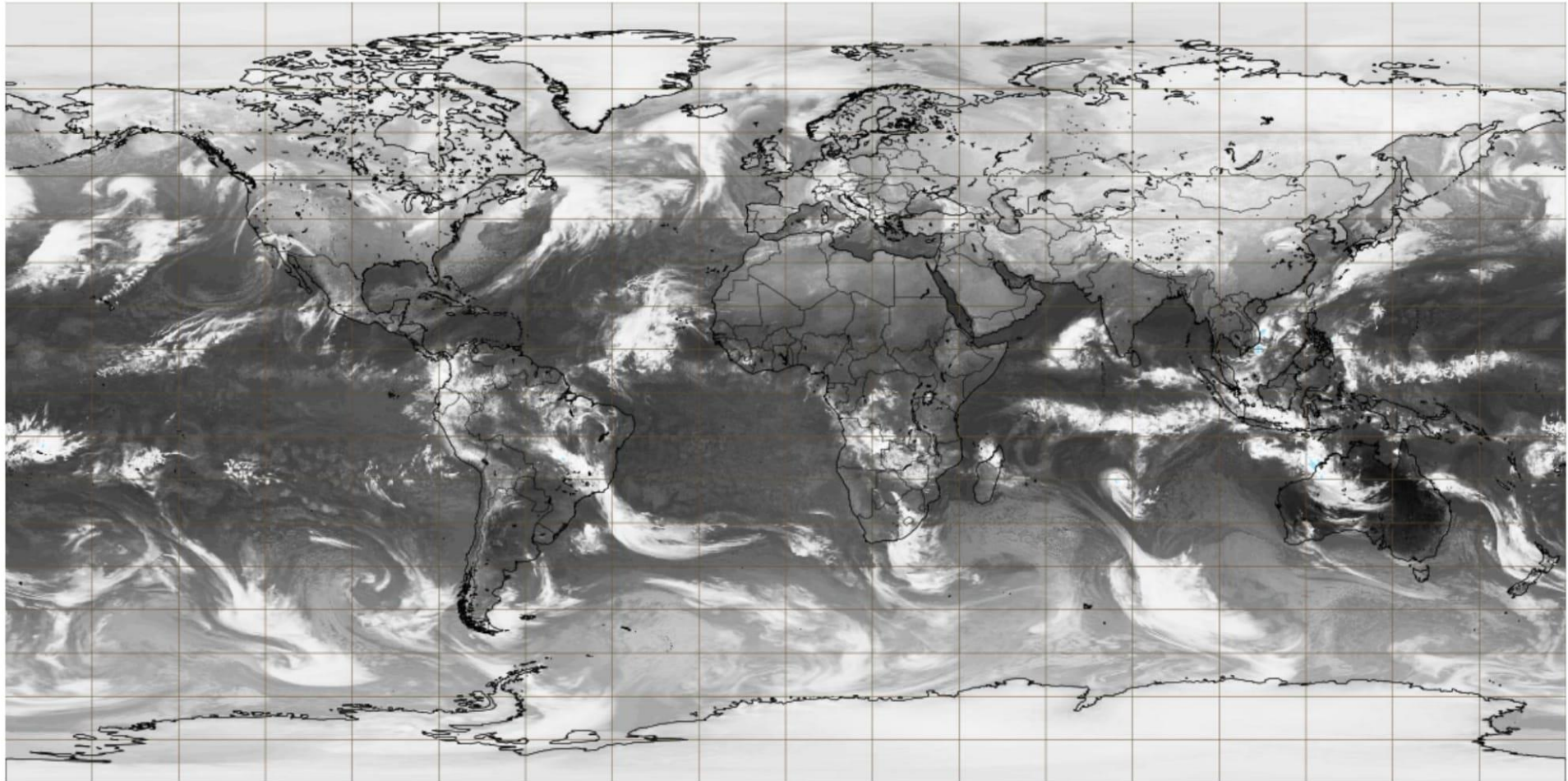
Simulated image: Infrared (IR) channel (C)

-120 -84 -66 -48 -30 -12 5 23 41 47



Simulated images - Infrared

Base time: Mon 07 Dec 2020 12 UTC, Valid time: Wed 09 Dec 2020 00 UTC, - T+36 h Area : Global



Simulated image: Infrared (IR) channel (C)

-120 -84 -66 -48 -30 -12 5 23 41 47



Simulated radar from NWP model

Simulated radar reflectivity from convection resolving NWP model

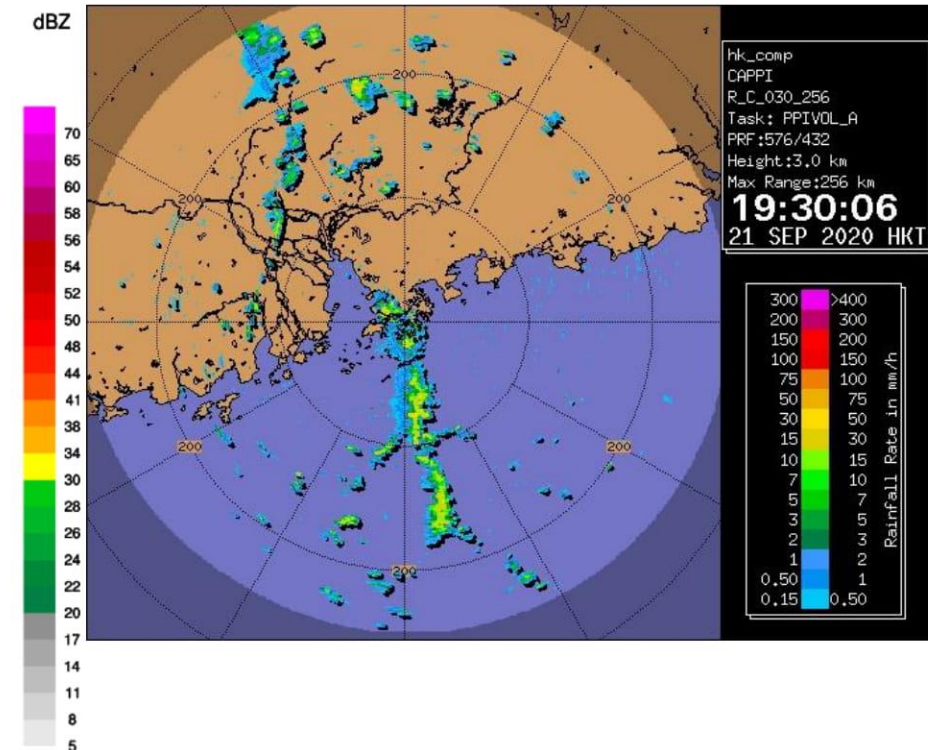
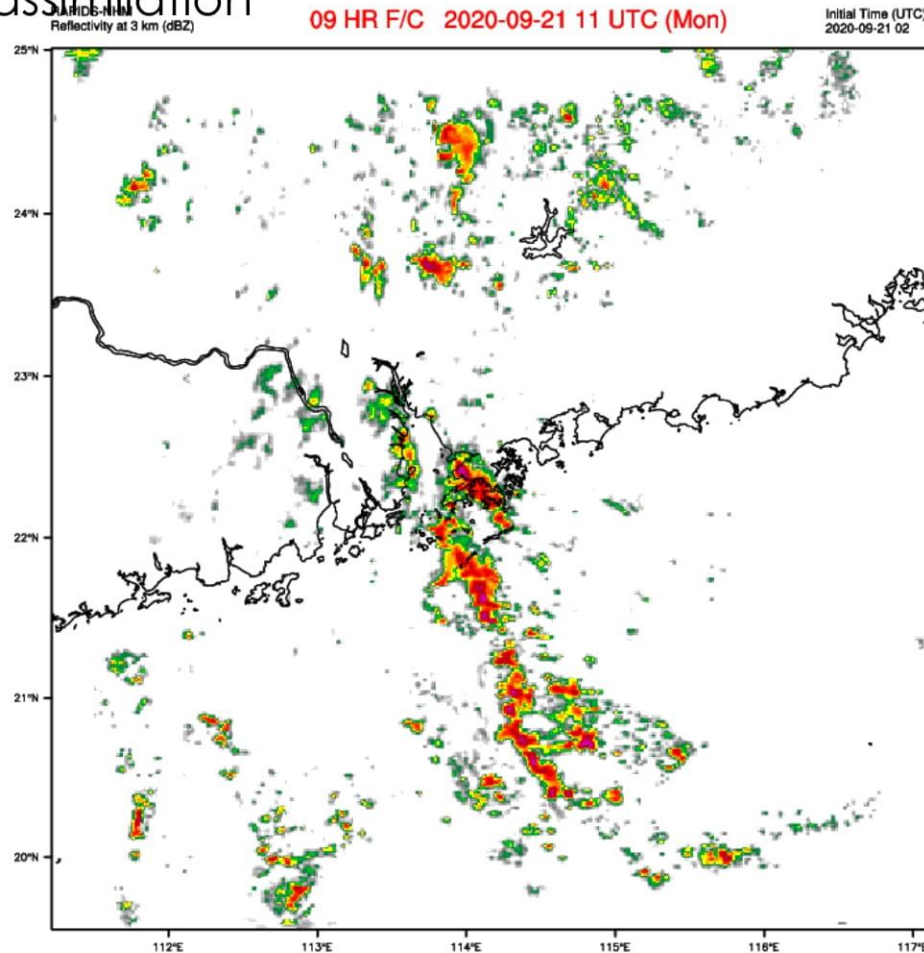
9-hr forecast simulated reflectivity on 3km level from 2km RAPIDS-NHM with the radar data assimilation

$Z = Z_r + Z_s + Z_g$ where

$$Z_r = 720 \frac{N_r}{\lambda_r^7}$$

$$Z_s = 720 \frac{|K_i|^2 \rho_s^2 N_{os}}{|K_w|^2 \rho_i^2 \lambda_s^7}$$

$$Z_g = 720 \frac{|K_i|^2 \rho_g^2 N_{og}}{|K_w|^2 \rho_i^2 \lambda_g^7}$$

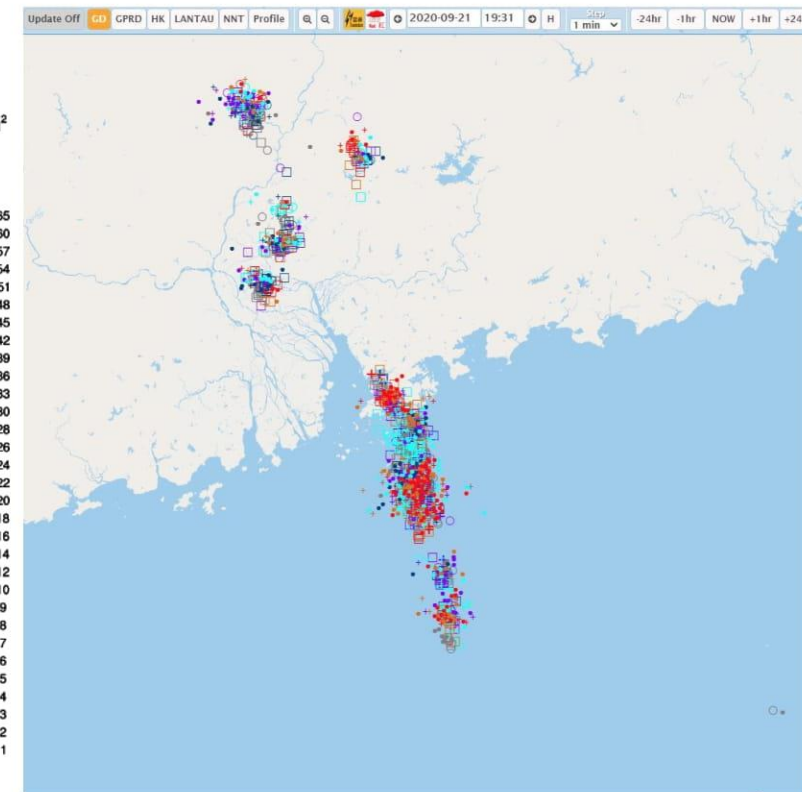
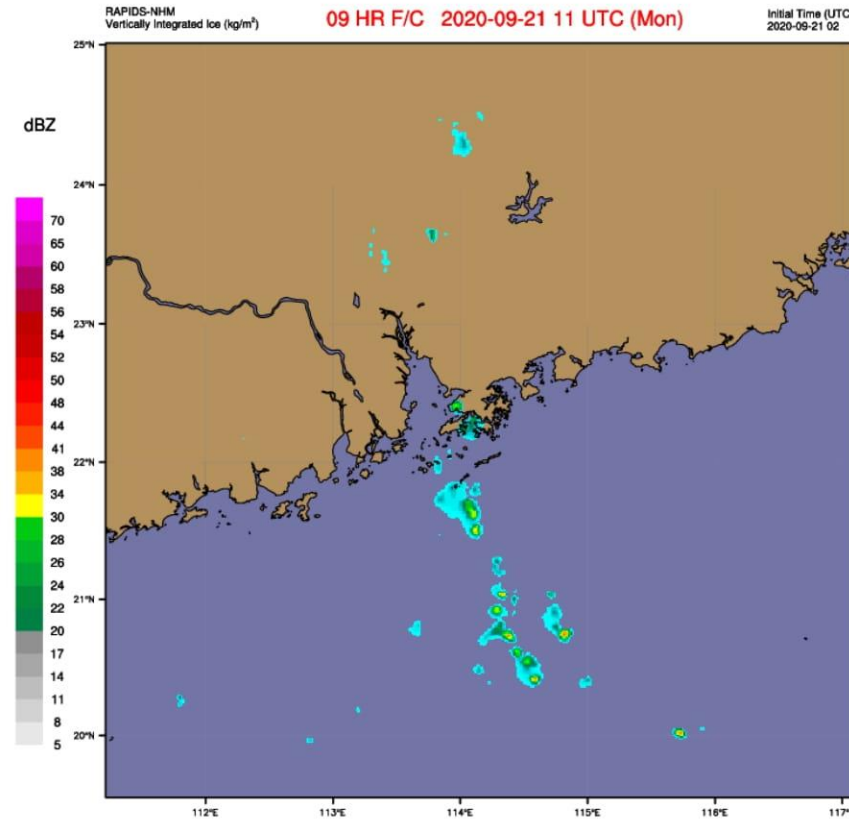
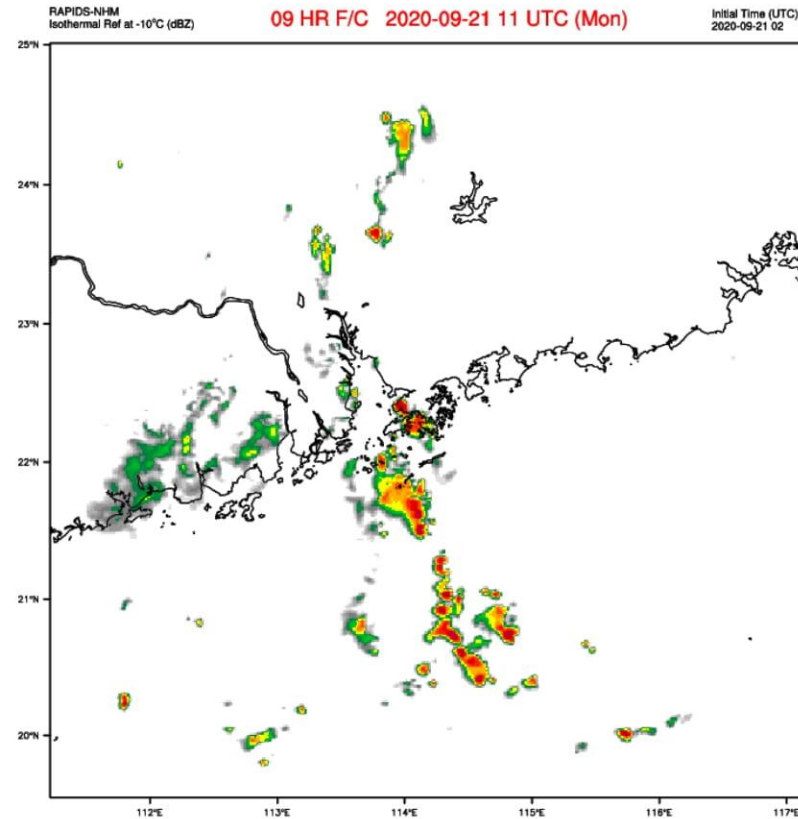


Vertically Integrated Ice

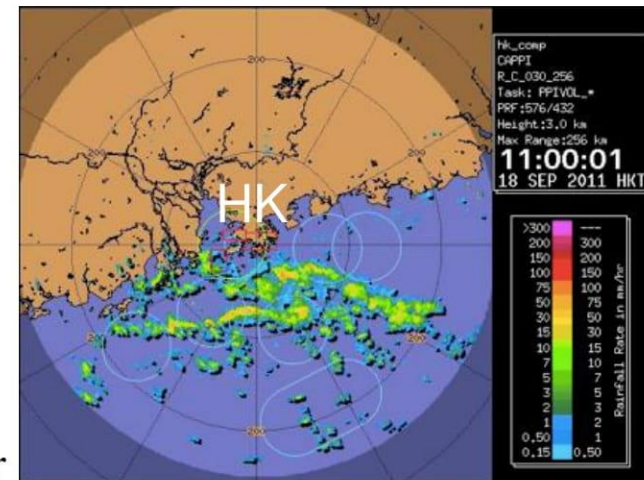
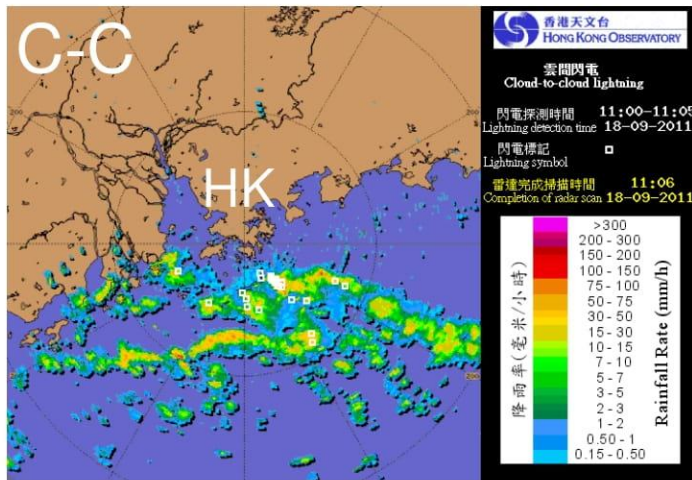
Isothermal reflectivity at -10 °C level

$$VII = 1000\pi\rho_i N_o^{3/7} \left(\frac{5.28 * 10^{-18}}{720} \right)^{4/7} \int_{H_{-10}}^{H_{-40}} Z^{4/7} dH$$

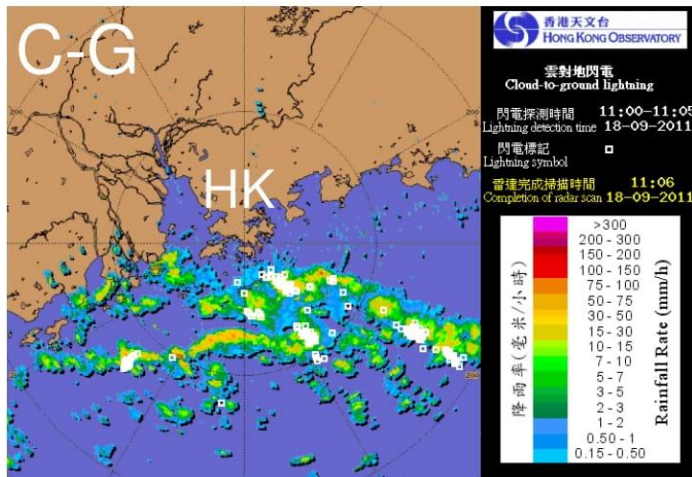
Actual lightning observation



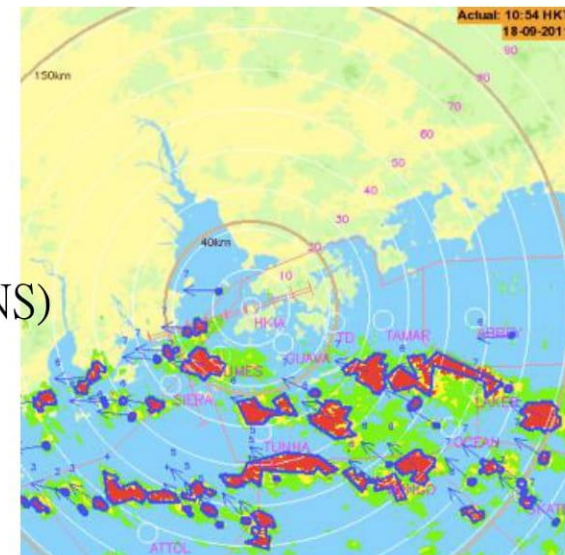
Airport Lightning and Thunderstorm Nowcast

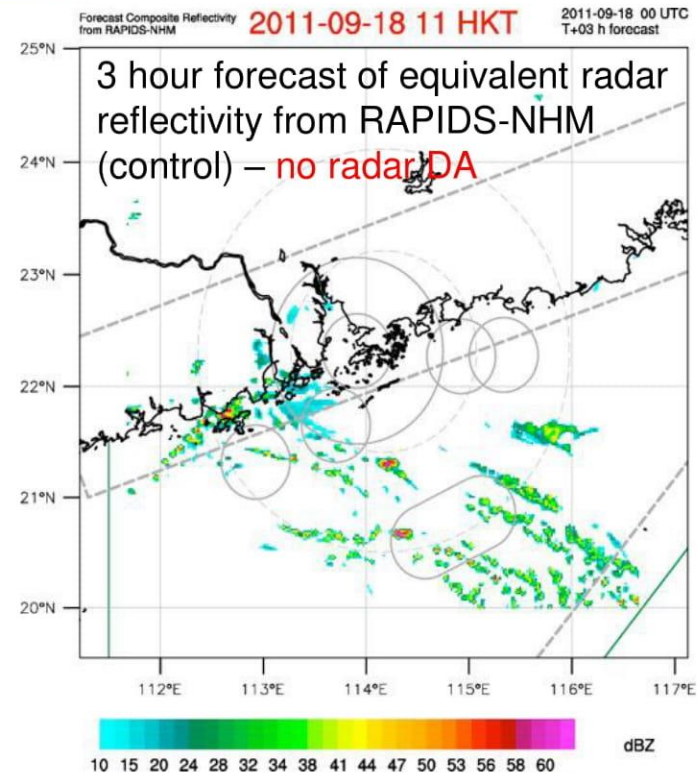
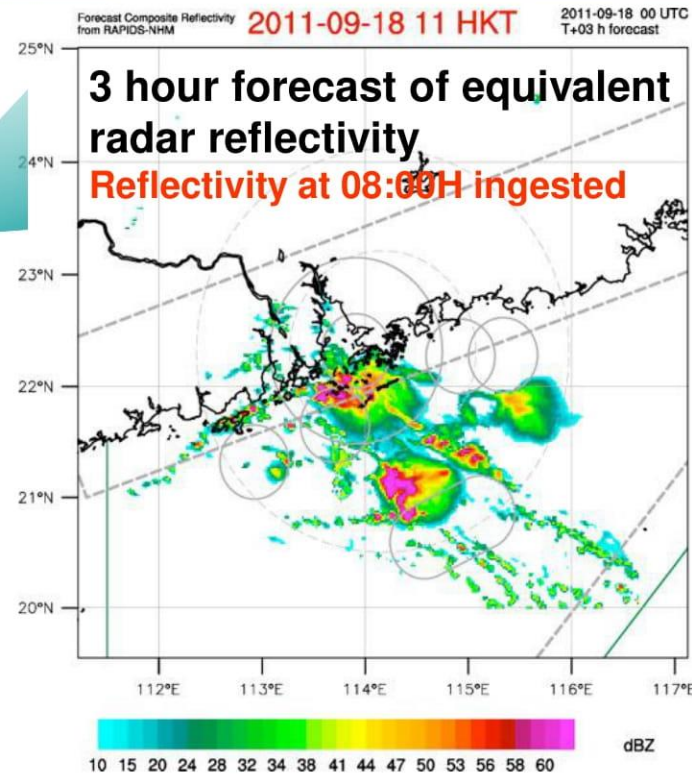
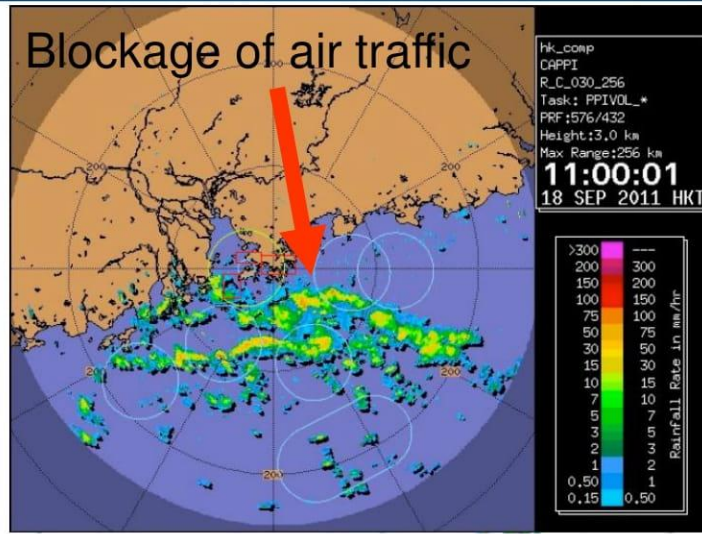
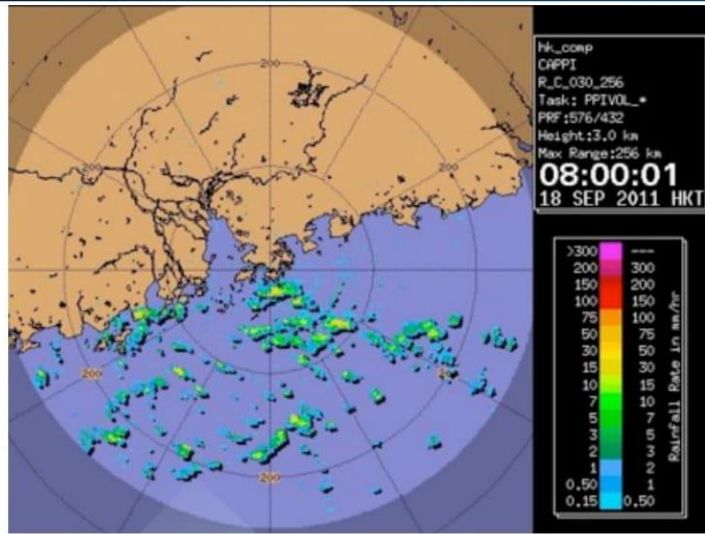


flight diversions due to air traffic blockage from S/SW



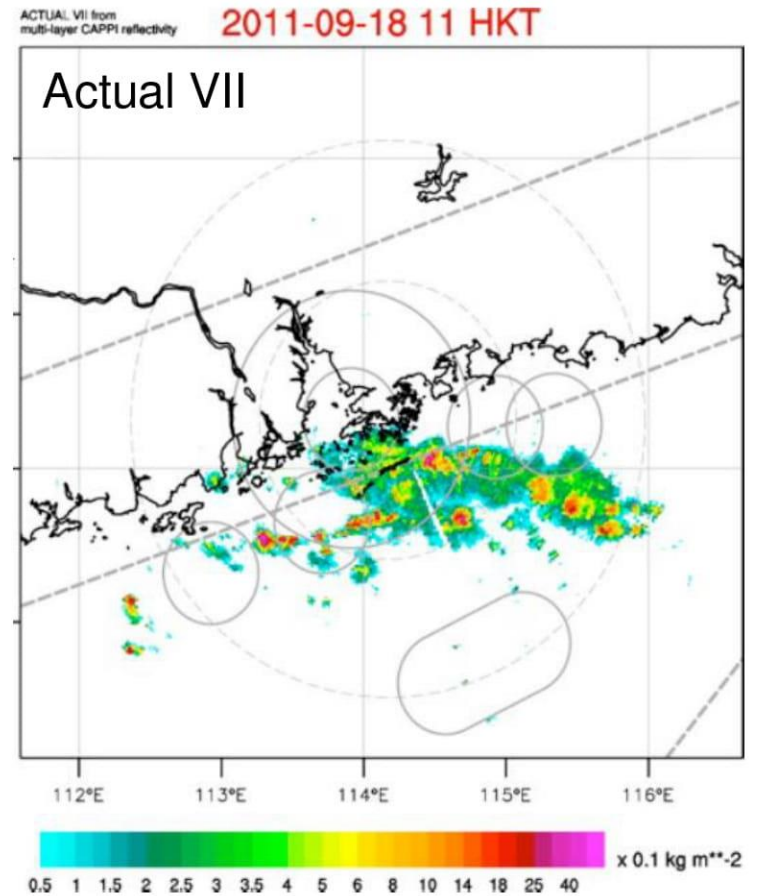
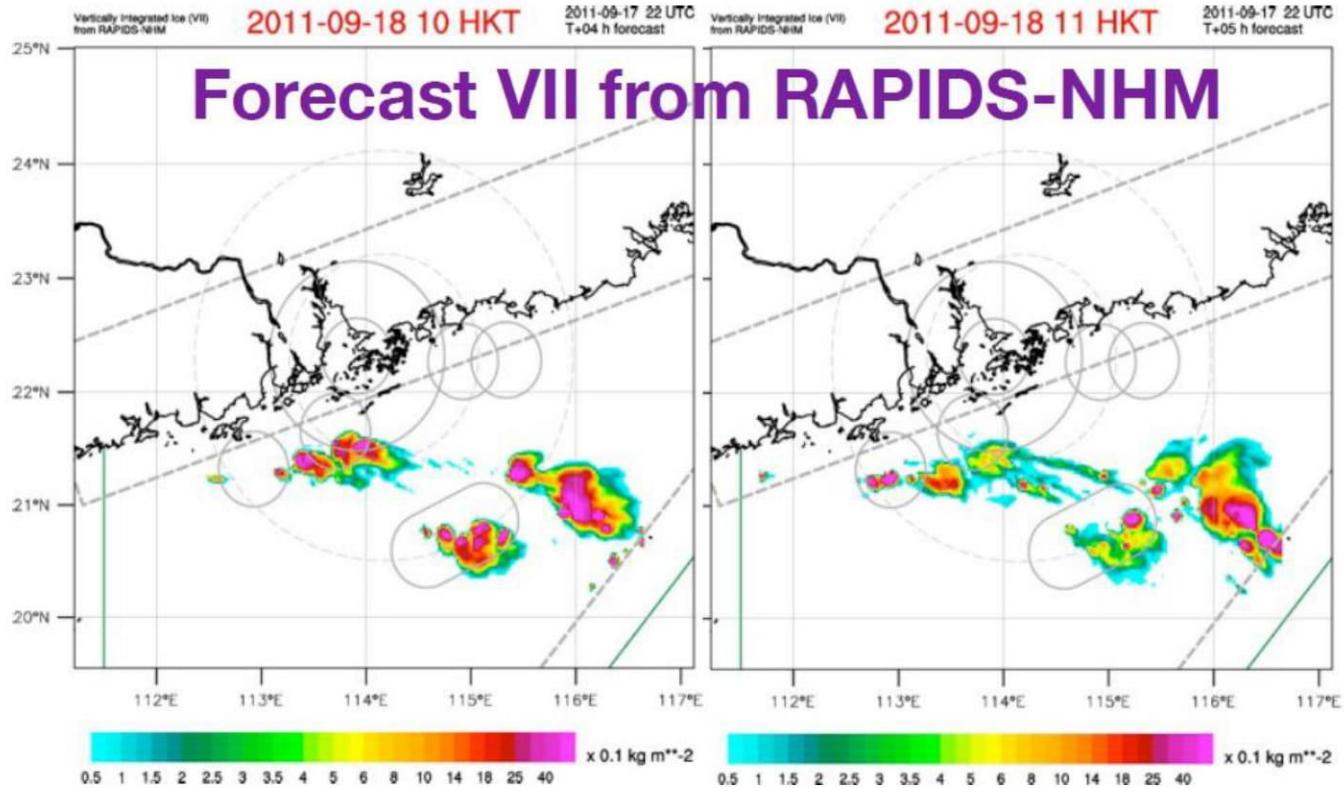
Alerts generated by the Aviation Thunderstorm Nowcasting System (ATNS)





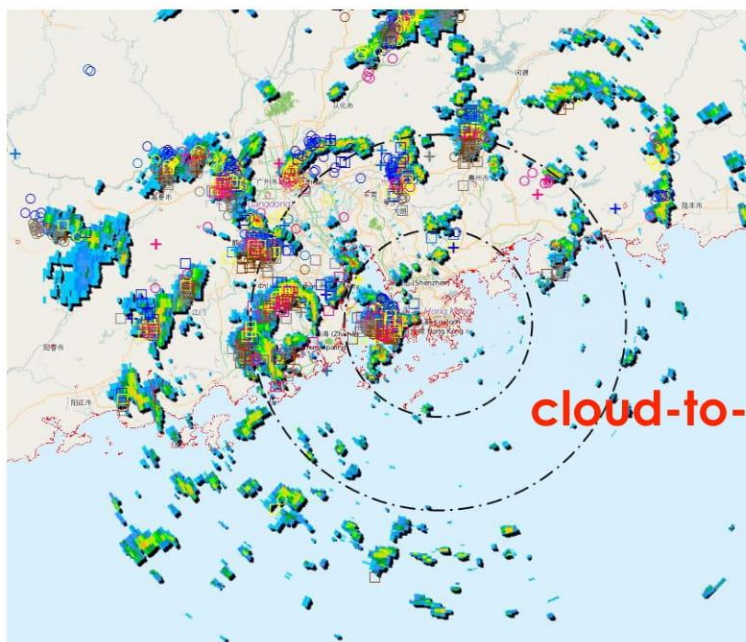
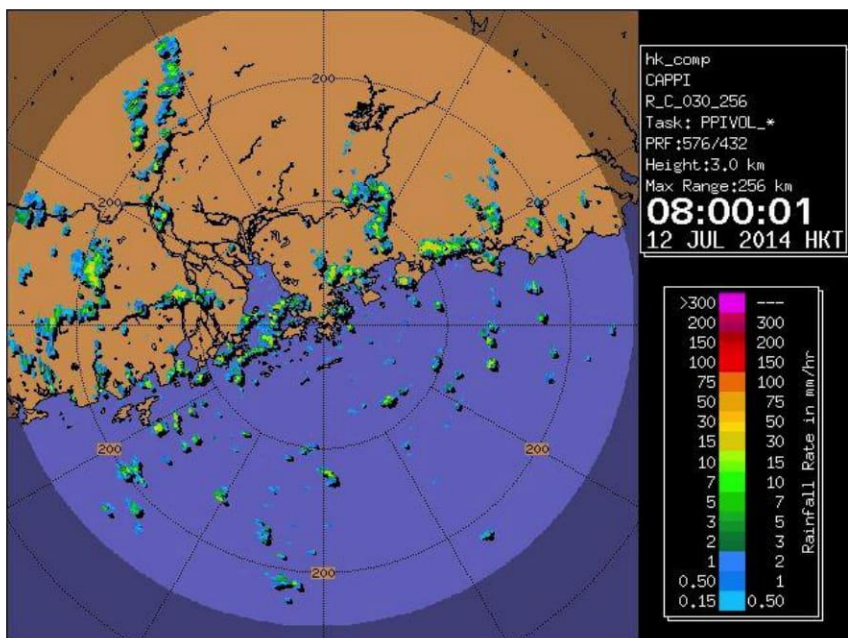
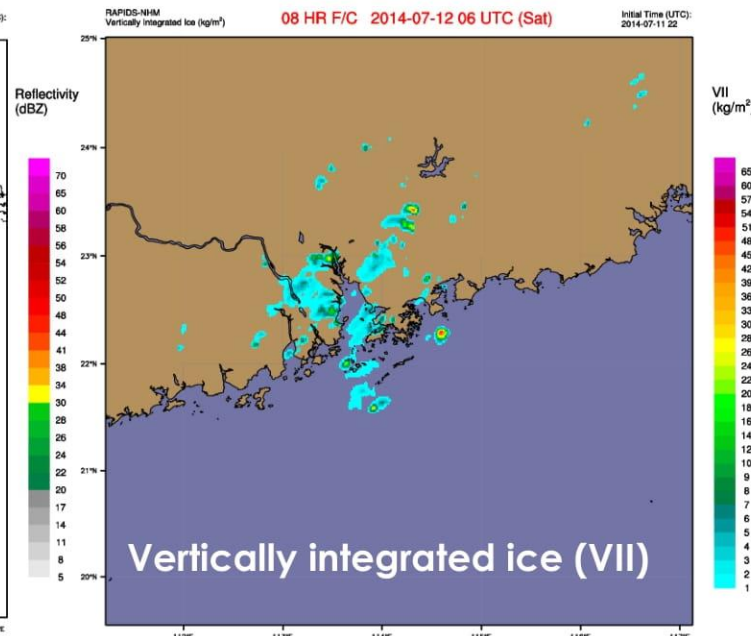
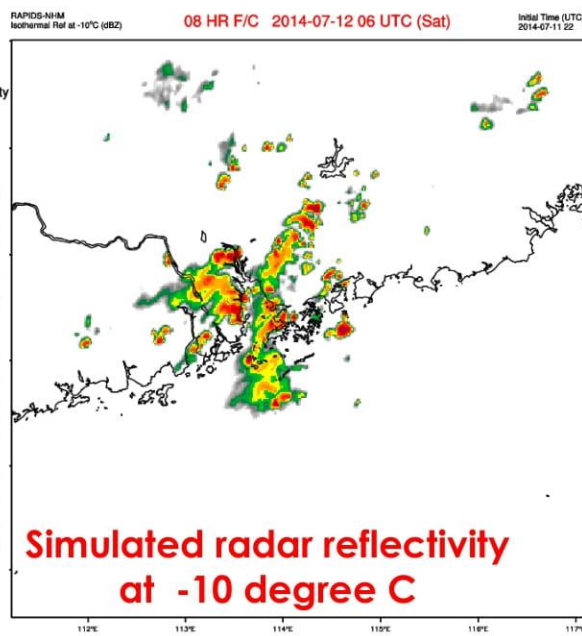
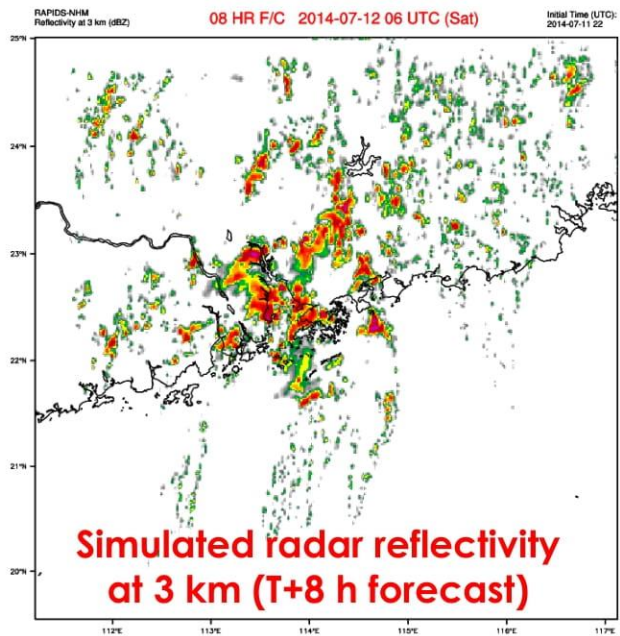
Vertically Integrated Ice

$$VII = 1000\pi\rho_i N_o^{3/7} \left(\frac{5.28 * 10^{-18}}{720}\right)^{4/7} \int_{H_{-10}}^{H_{-40}} Z^{4/7} dH$$



H : Heights of isotherms from RAPIDS-NHM analysis or forecast

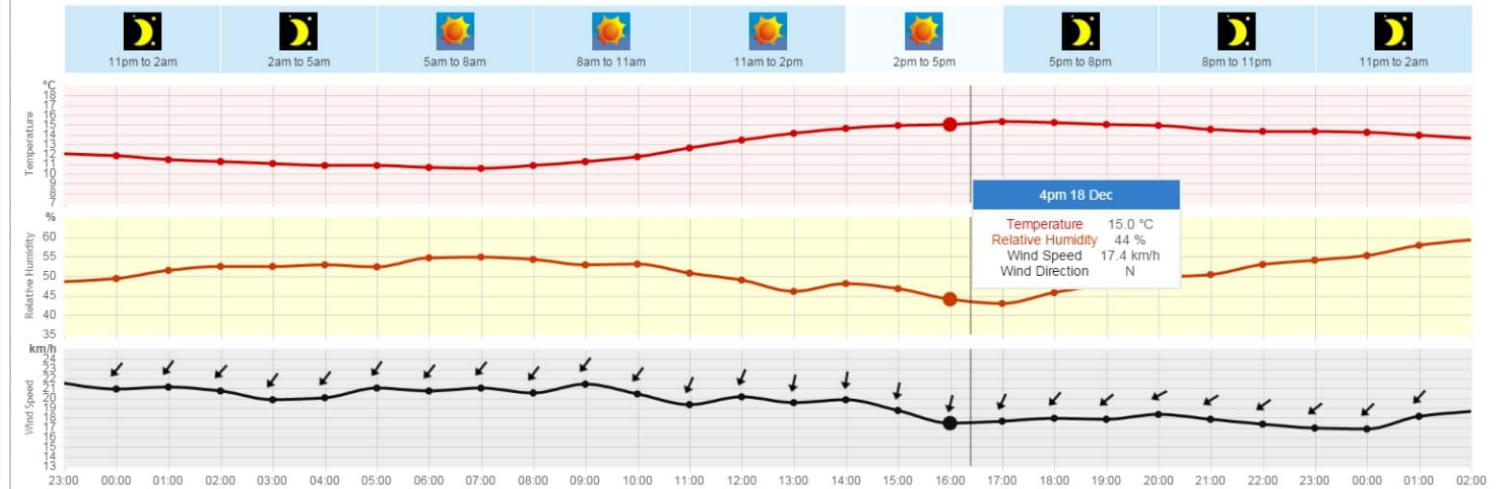
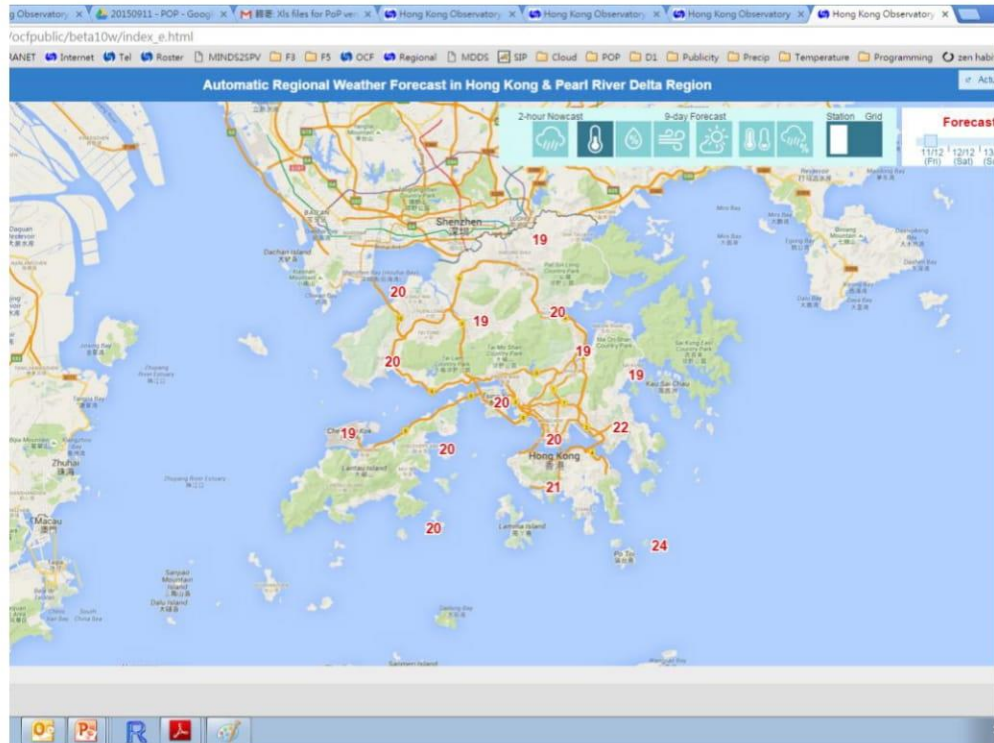
$$VII = 1000\pi\rho_i N_o^{3/7} \left(\frac{5.28 * 10^{-18}}{720}\right)^{4/7} \int_{H_{-10}}^{H_{-40}} Z^{4/7} dH$$



From Direct Model Output to "Weather Generator"

Automatic Regional Weather Forecast (ARWF)

WebGIS version: <http://maps.weather.gov.hk/ocf/>



Integrating ARWF with MyObservatory on iOS and Android platforms

The image displays four screenshots of the MyObservatory app interface, demonstrating the integration of ARWF (Automatic Rainfall Forecast) with weather data on iOS and Android platforms.

Leftmost Screenshot (iOS): Shows the main interface for Jordan on 17 February 2016 (Wednesday) at 16:02. It includes a 5-day forecast and an Automatic Forecast (Jordan) section with a temperature graph and rain chance data.

Time	Temp	Rain	Wind
05H	15°C	79%	7 km/h
08H	15°C	75%	8 km/h
11H	17°C	67%	8 km/h
14H	18°C	66%	9 km/h
17H	17°C	70%	8 km/h
20H	17°C	75%	7 km/h
23H	16°C	77%	6 km/h
02H	16°C	-	E

Second Screenshot (Android): Shows the main interface for The Peak on 08 Mar 2016 (Tuesday) at 15:25. It includes a 5-day forecast and an Automatic Forecast (The Peak) section with a temperature graph and rain chance data.

Time	Temp	Rain	Wind
05H	15°C	79%	7 km/h
08H	15°C	75%	8 km/h
11H	17°C	67%	8 km/h
14H	18°C	66%	9 km/h
17H	17°C	70%	8 km/h
20H	17°C	75%	7 km/h
23H	16°C	77%	6 km/h
02H	16°C	-	E

Third Screenshot (Android): Shows the main interface for The Peak on 08 Mar 2016 (Tuesday) at 15:25. It includes a 5-day forecast and an Automatic Forecast (The Peak) section with a temperature graph and rain chance data.

Time	Temp	Rain	Wind
05H	15°C	79%	7 km/h
08H	15°C	75%	8 km/h
11H	17°C	67%	8 km/h
14H	18°C	66%	9 km/h
17H	17°C	70%	8 km/h
20H	17°C	75%	7 km/h
23H	16°C	77%	6 km/h
02H	16°C	-	E

Rightmost Screenshot (Android): Shows the main interface for The Peak on 08 Mar 2016 (Tuesday) at 15:25. It includes a 5-day forecast and an Automatic Forecast (The Peak) section with a temperature graph and rain chance data.

Time	Temp	Rain	Wind
05H	15°C	79%	7 km/h
08H	15°C	75%	8 km/h
11H	17°C	67%	8 km/h
14H	18°C	66%	9 km/h
17H	17°C	70%	8 km/h
20H	17°C	75%	7 km/h
23H	16°C	77%	6 km/h
02H	16°C	-	E

自動分區天氣預報網頁 Automatic Regional Weather Forecast Website

一站式自動天氣預報
One-stop platform to provide automatic weather forecast

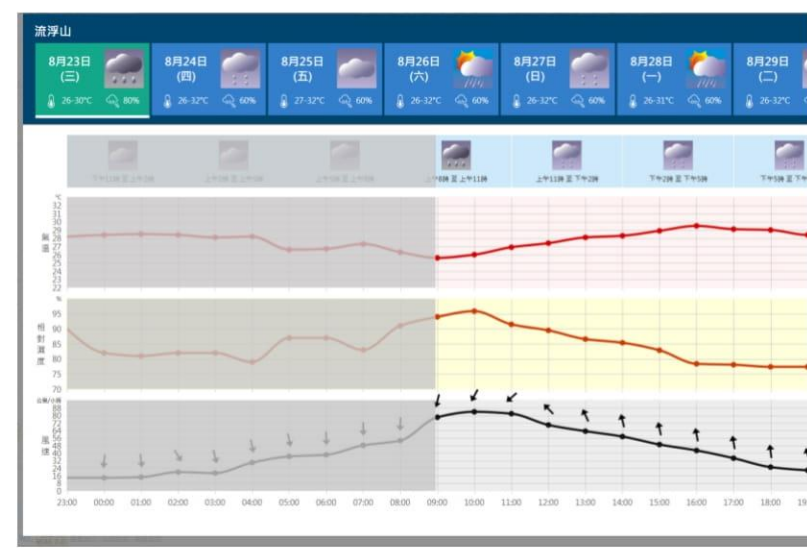


兩小時降雨臨近預報
2-hour rainfall nowcast

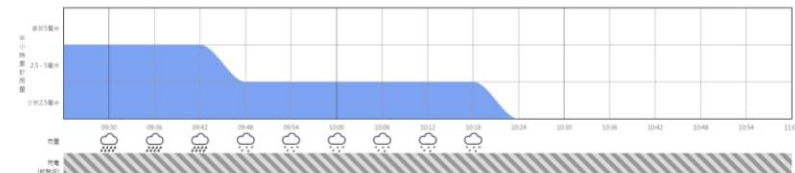


提供香港及珠三角地區未來九天定點的天氣預報及每日全港降雨的概率預報

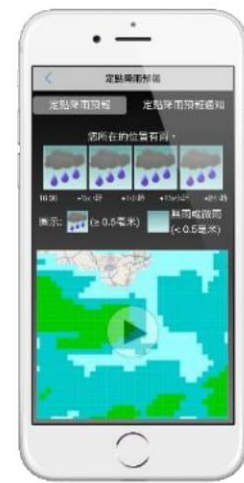
To provide weather forecast and the probability of precipitation at several stations in Hong Kong and grid boxes over the Pearl River Delta Region



未來兩小時的預測降雨分佈和動畫
Rainfall distribution map for the next 2 hours

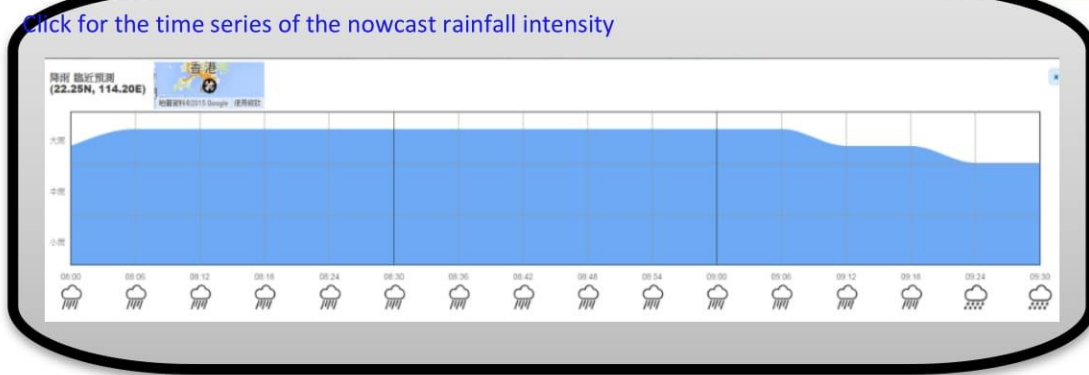


網址/URL : http://maps.weather.gov.hk/ocf/index_uc.html



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

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



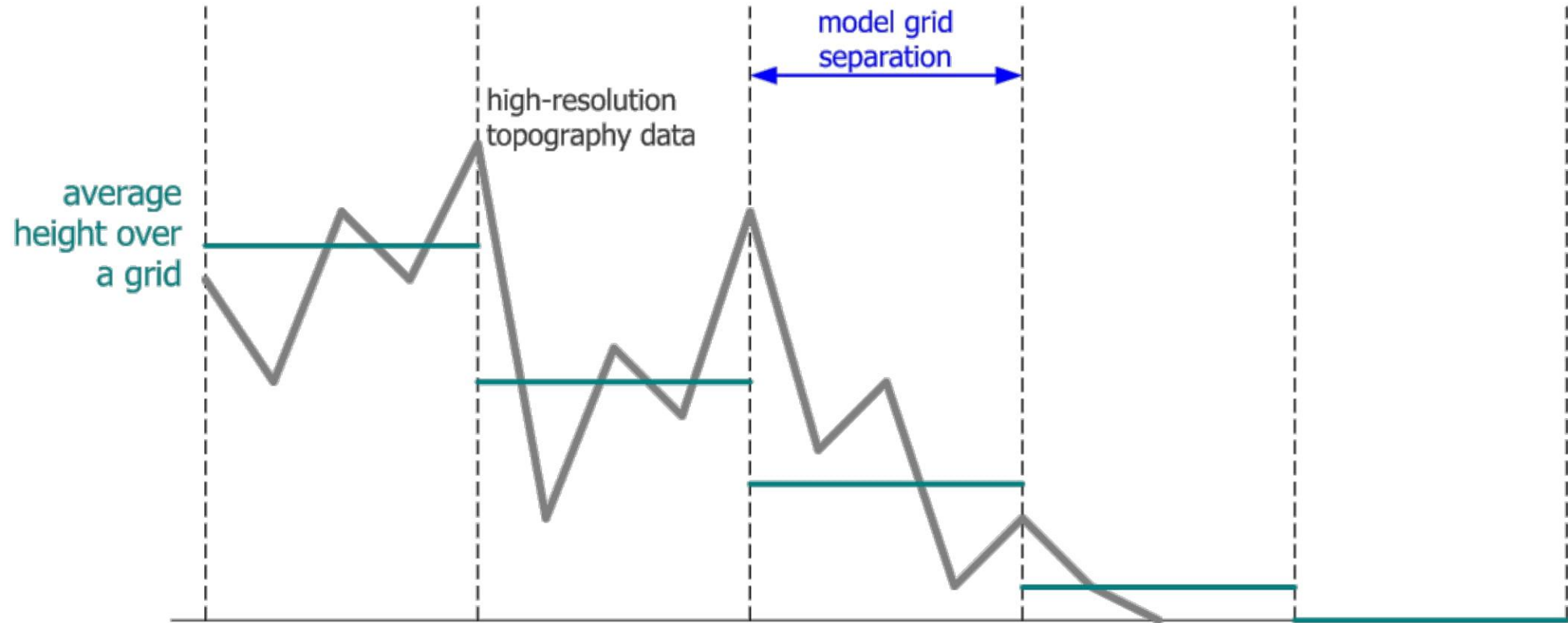
2015年7月22日，天文台發出黃色暴雨警告接近12小時，而山泥傾瀉警告亦生效超過6小時。強降雨區在早上一段時間幾乎停留在香港南部。

On 22 July 2015, the Amber Rainstorm Warning Signal issued by the Observatory lasted for nearly 12 hours and the Landslip Warning was also in force for more than 6 hours. The area of intense rain remained almost stationary over the southern part of Hong Kong for a prolonged period in the morning

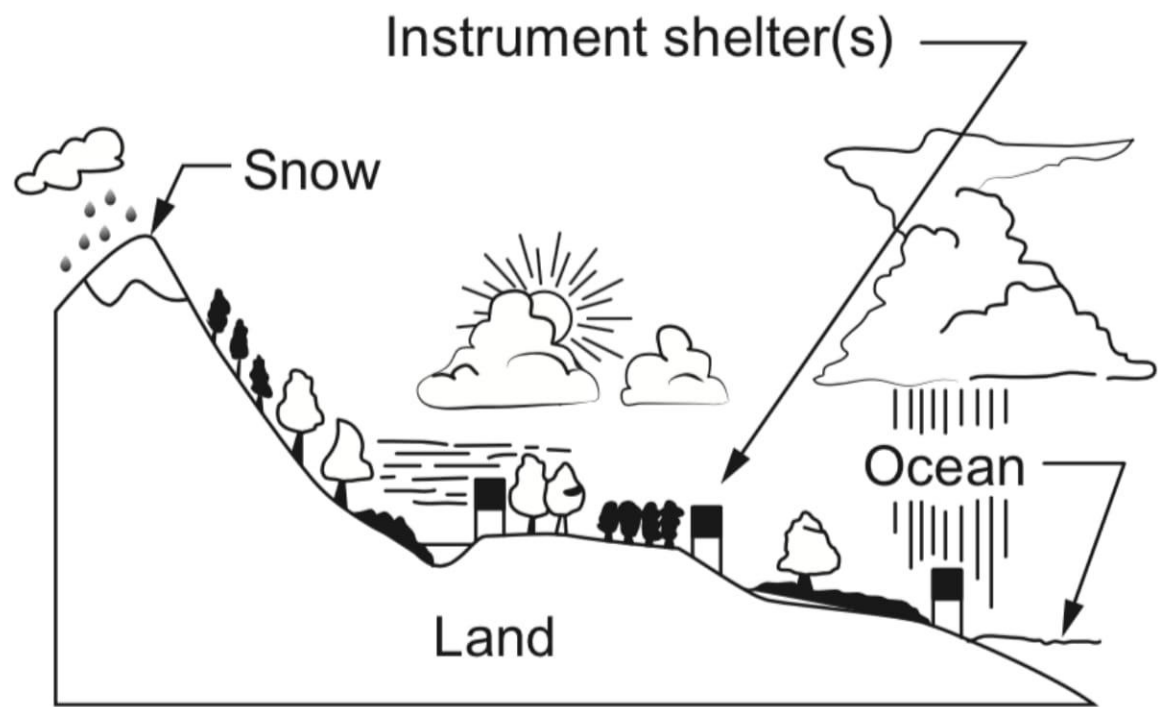


WHY MODEL POST-PROCESSING ?

Consideration of Terrain and Coastal Effects

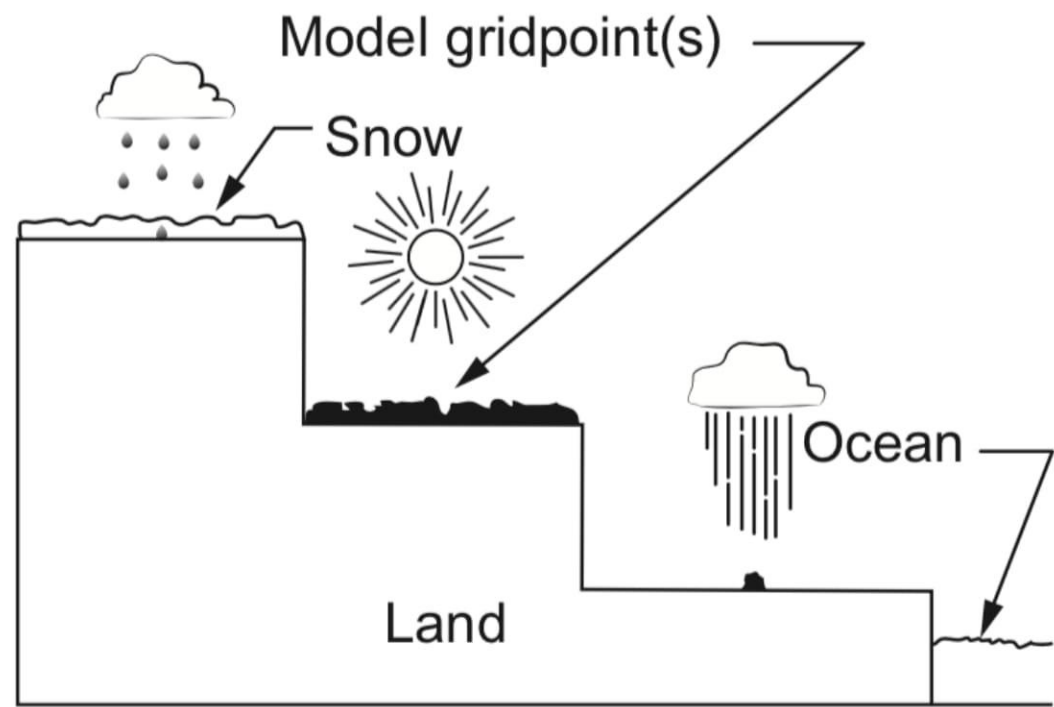


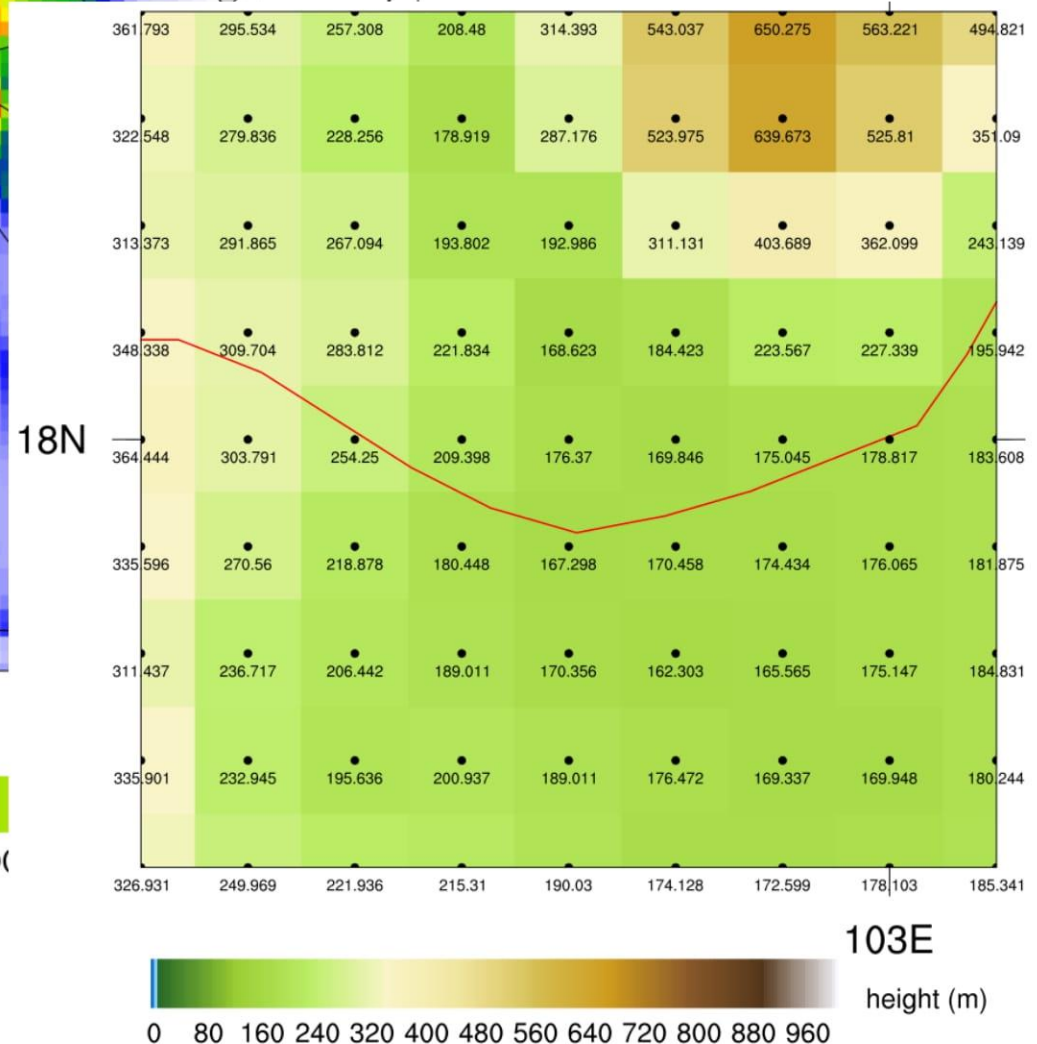
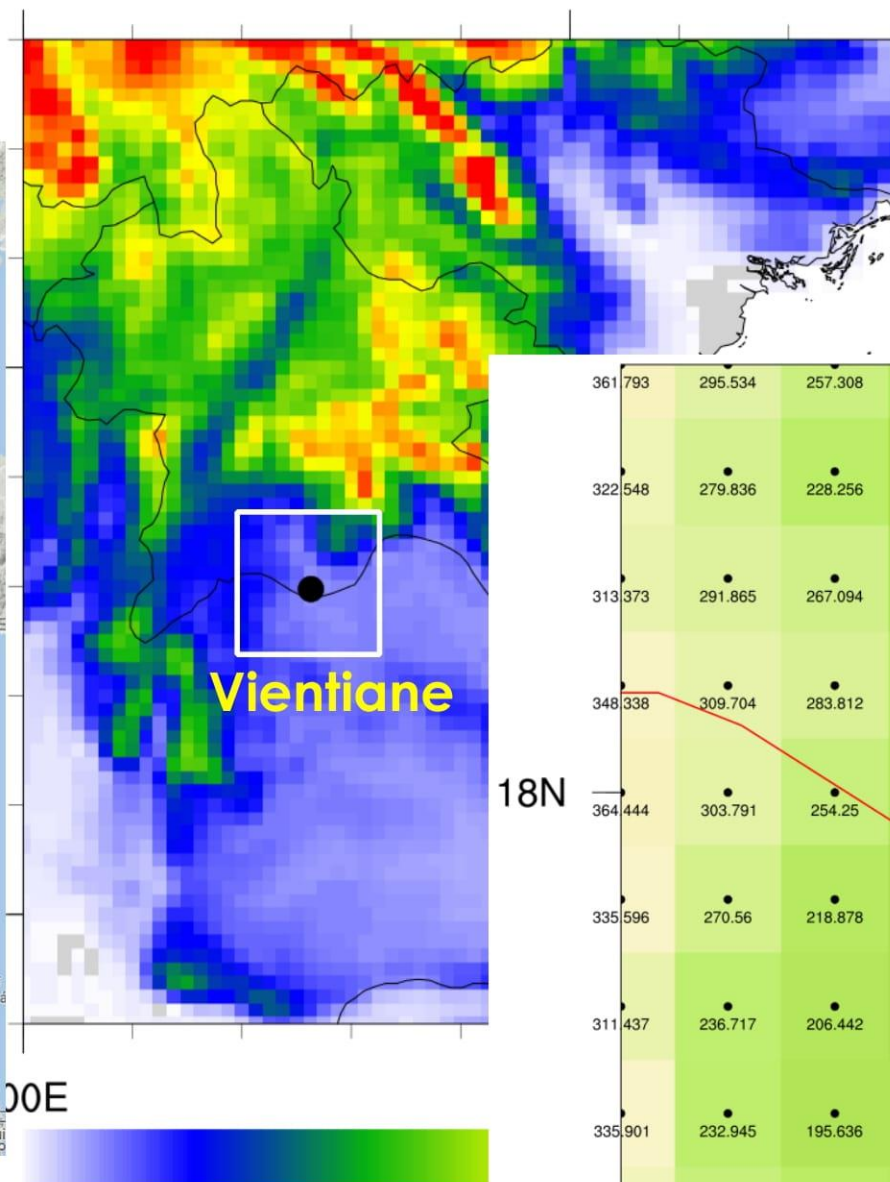
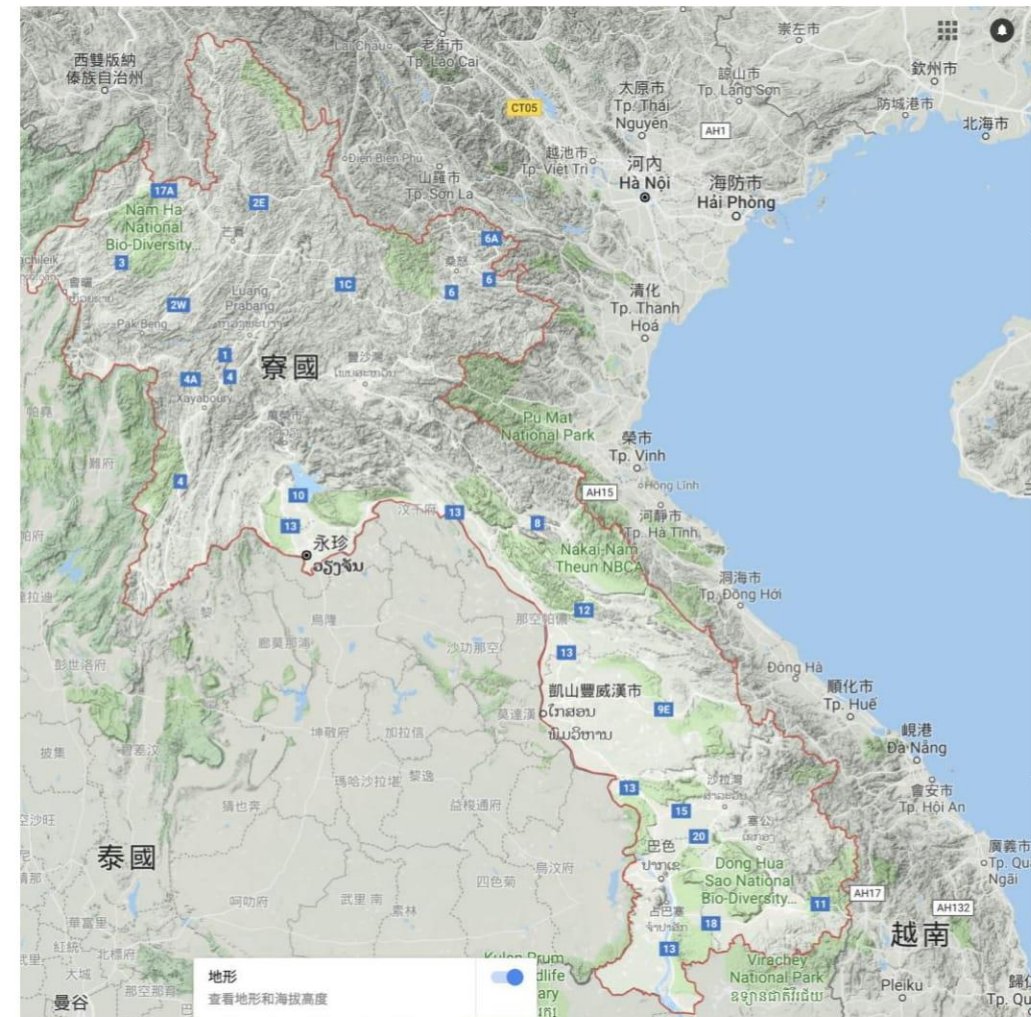
Real world



Vs.

Model world



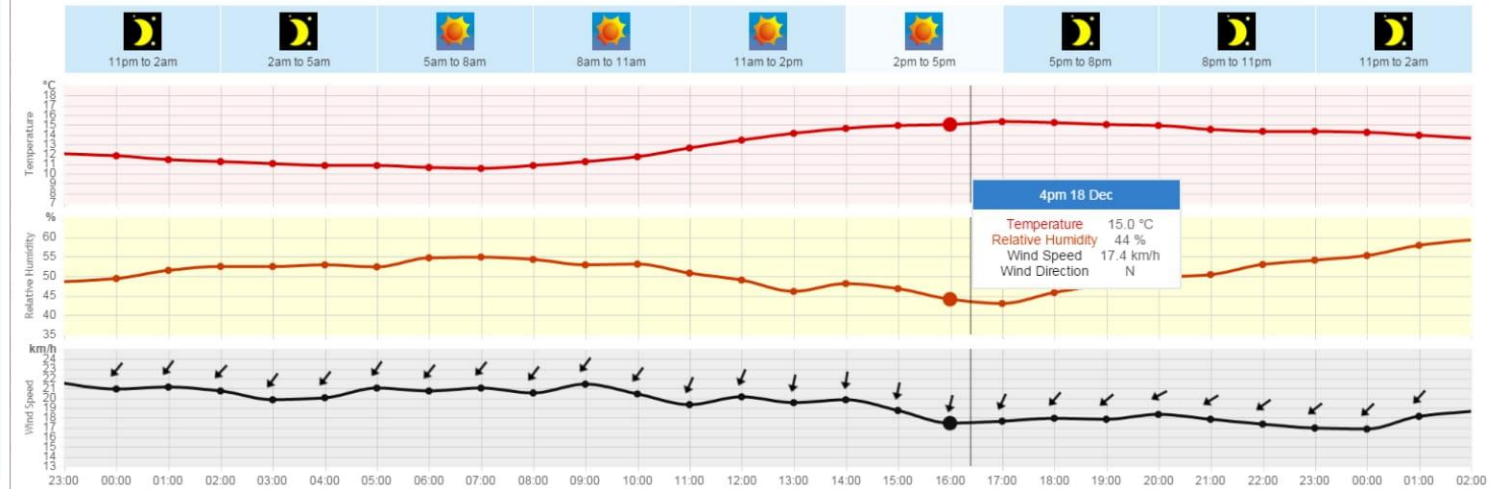
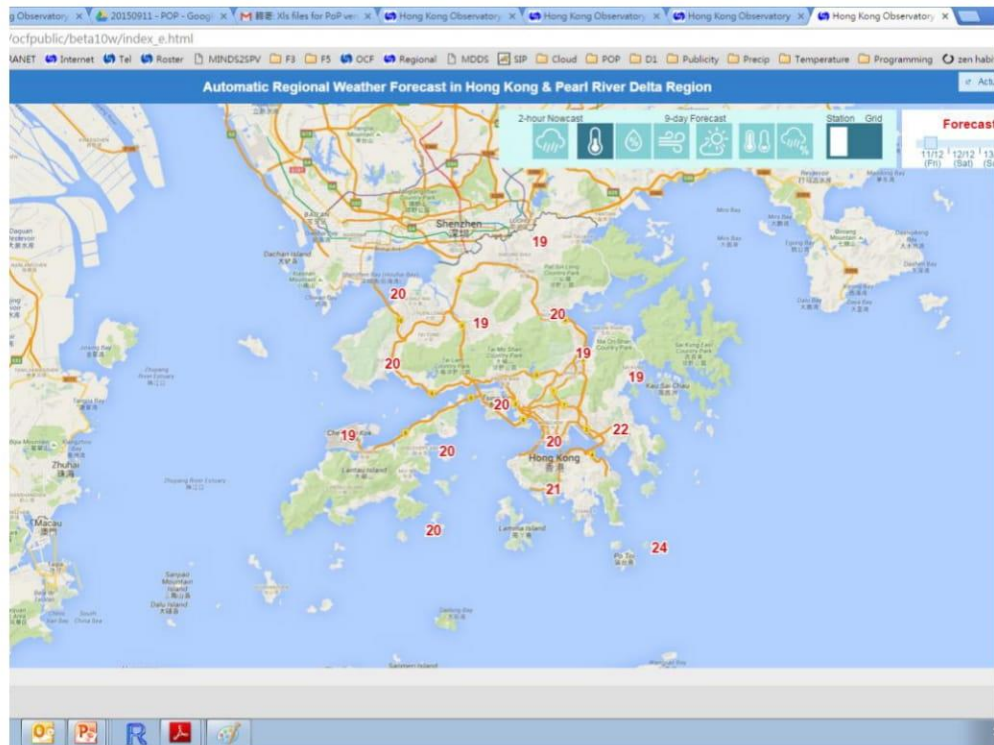


0 250 500 750 1000

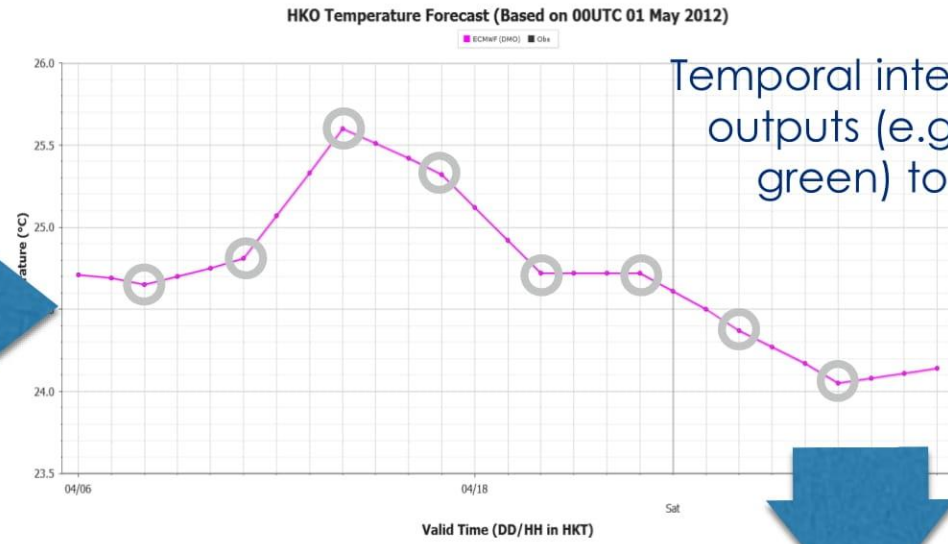
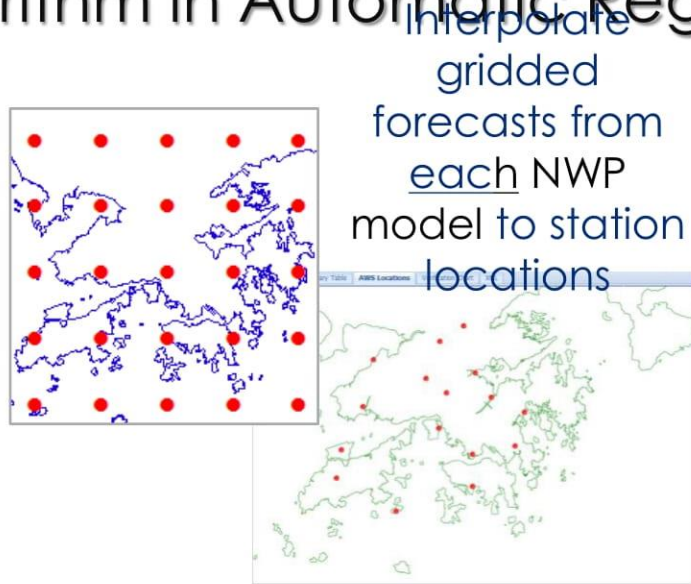
0 80 160 240 320 400 480 560 640 720 800 880 960 height (m)

Automatic Regional Weather Forecast (ARWF)

WebGIS version: <http://maps.weather.gov.hk/ocf/>

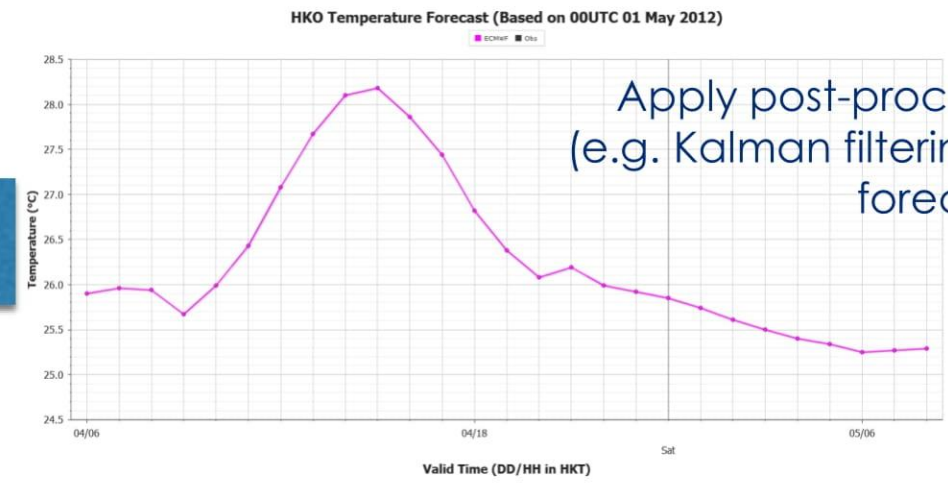
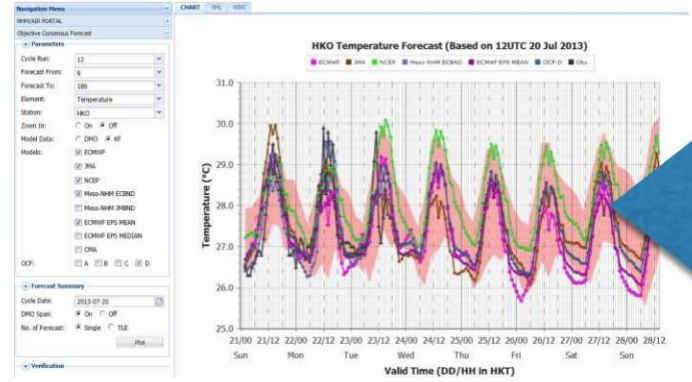


Algorithm in Automatic Regional Weather Forecast



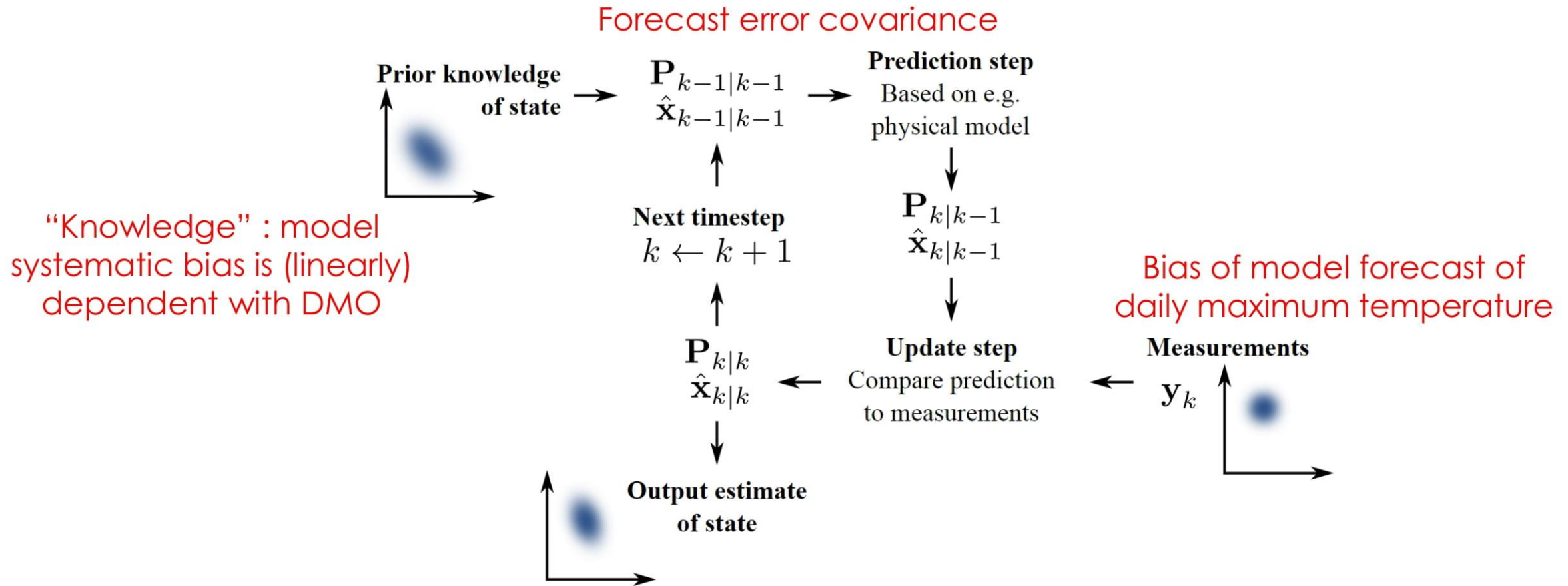
Temporal interpolation of model outputs (e.g. every 3 hours in green) to hourly interval

calculate consensus based on past 30-day performance



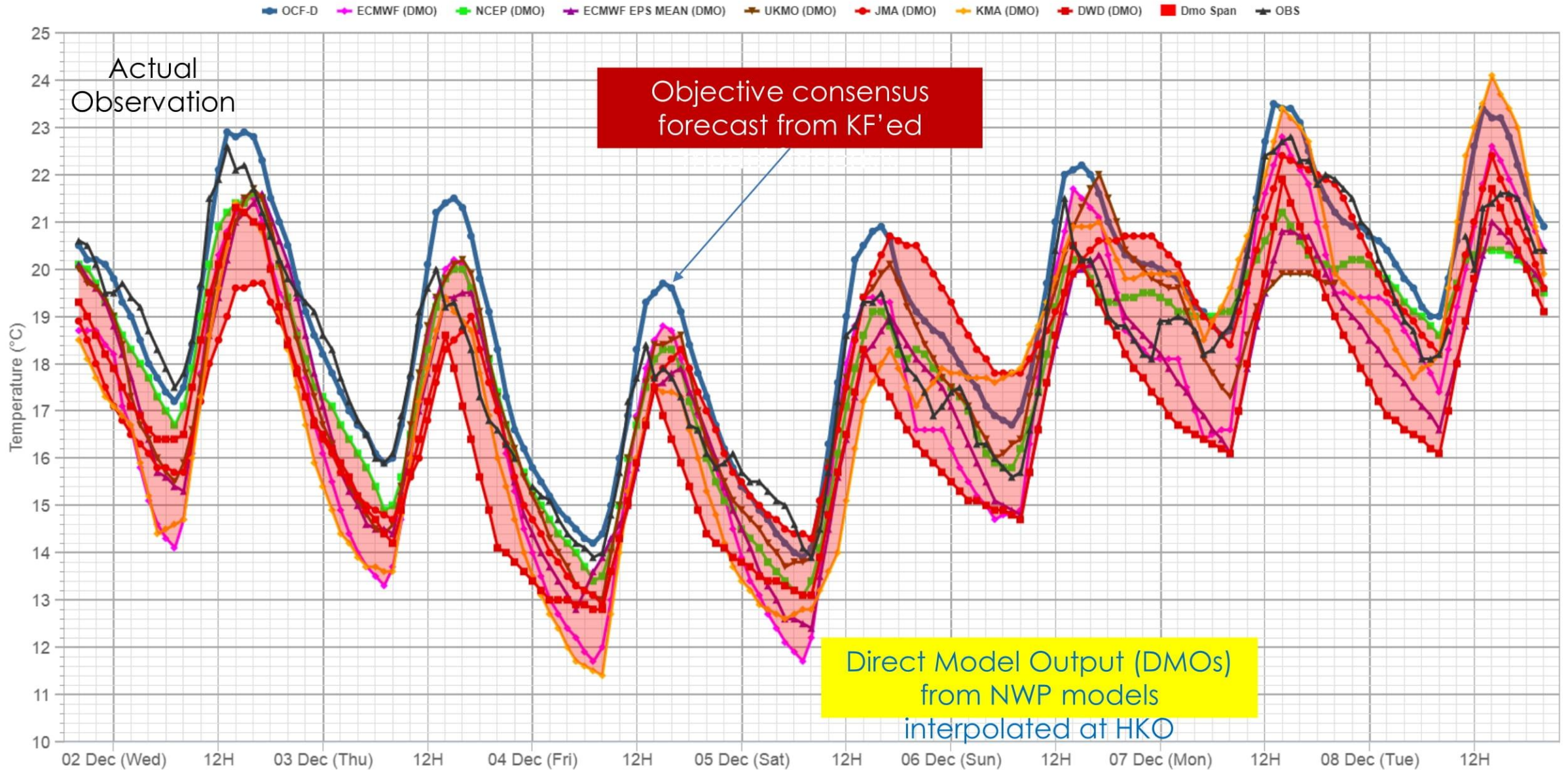
Apply post-processing algorithm (e.g. Kalman filtering for temperature forecast)

- Example of KF in model post-processing: adaptive method to correct NWP forecast (bias) of daily maximum temperature



→ Kalman filter post-processing thus target to estimate (predict) and update bias based on previous model forecasts and observed values

Hong Kong Observatory Temperature Forecast (Based on 12UTC 01 Dec 2020)



Forecast Verification Metric (continuous variables)

- Bias

$$\text{Mean Error (ME)} = \frac{1}{N} \sum_{i=1}^N (F_i - O_i) \quad \text{Perfect: 0}$$

$$\text{Multiplicative Bias} = \frac{\frac{1}{N} \sum_{i=1}^N F_i}{\frac{1}{N} \sum_{i=1}^N O_i} \quad \text{Perfect: 1}$$

- Accuracy measures

Mean Absolute Error (MAE)

$$= \frac{1}{N} \sum_{i=1}^N |F_i - O_i|$$

Does not take into account direction of error as ME does

Root Mean Square Error (RMSE)

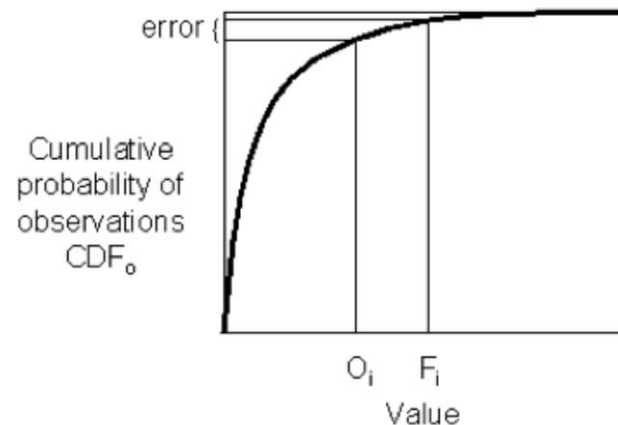
$$= \sqrt{\frac{1}{N} \sum_{i=1}^N (F_i - O_i)^2}$$

More sensitive to large errors than MAE

Linear Error in Probability Space (LEPS)

$$= \frac{1}{N} \sum_{i=1}^N |CDF(F_i) - CDF(O_i)|$$

- Not a widely-used measure
- Does not discourage the forecast of extreme values as MAE or RMSE does

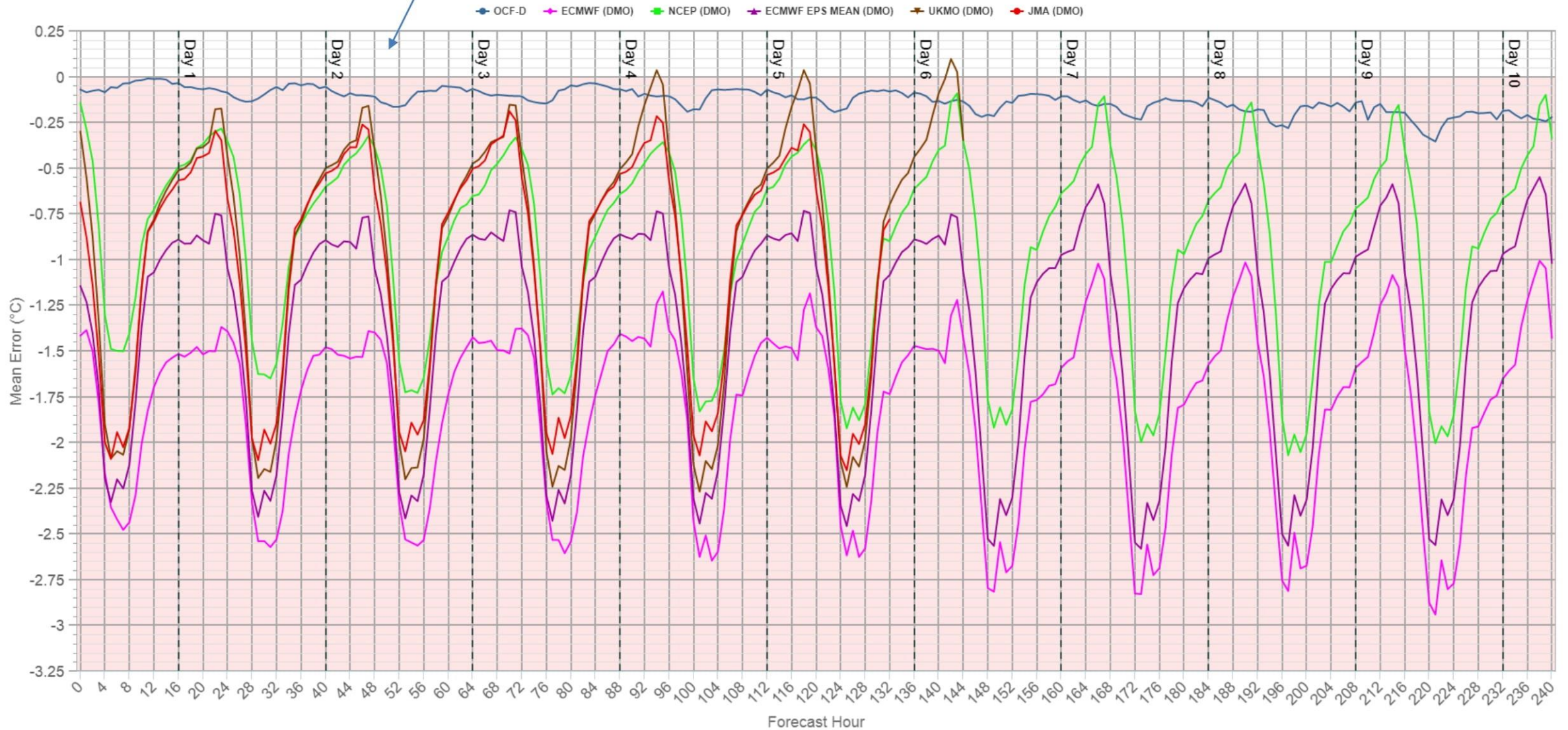


Mean Error (Bias)

Objective consensus forecast from KF'ed

Direct Model Output (DMOs) from NWP models interpolated at HKO

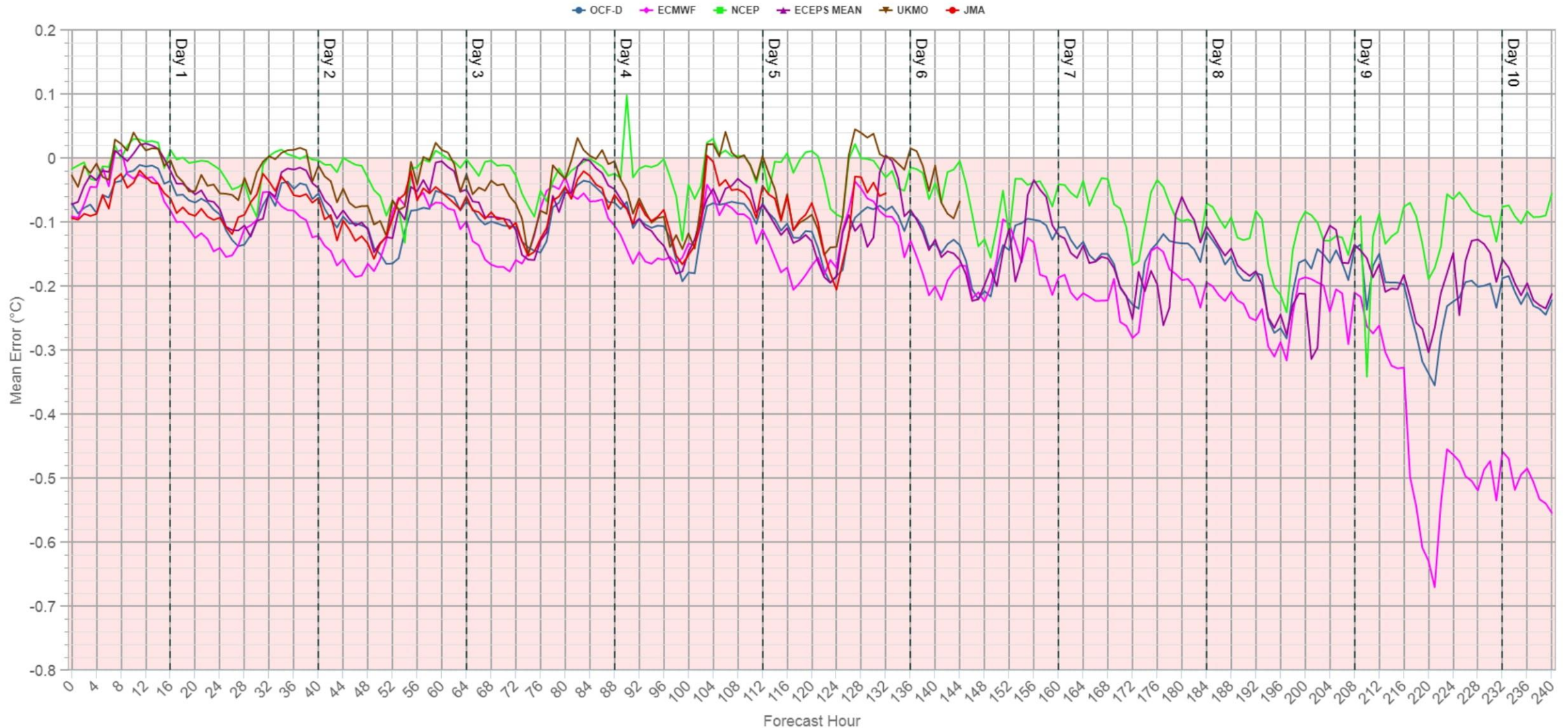
Hong Kong Observatory Temperature Verification (Between 01 Apr 2020 and 30 Nov 2020 00Z)



Mean Error (Bias)

Post-processed NWP model forecasts using Kalman filter

Hong Kong Observatory Temperature Verification (Between 01 Apr 2020 and 30 Nov 2020 00Z)

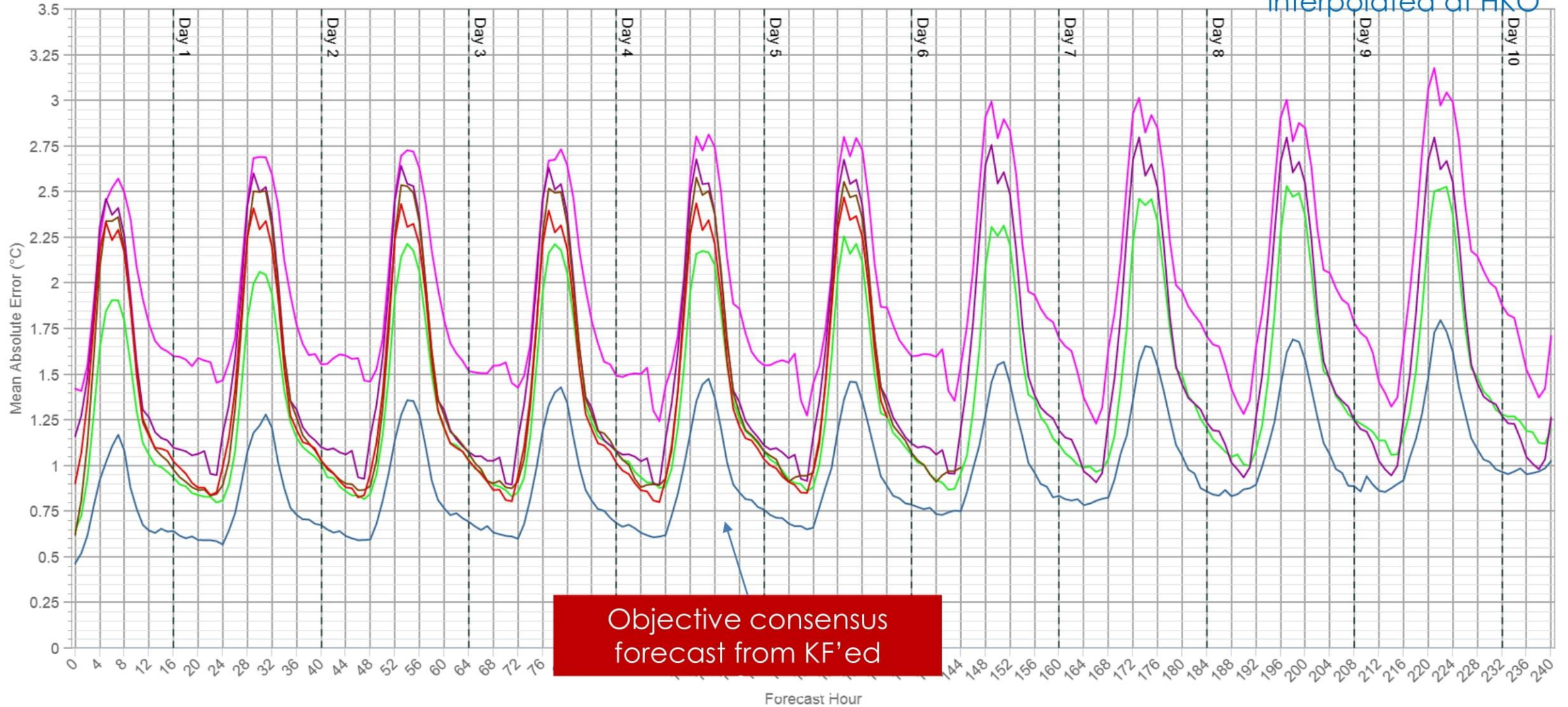


Mean Absolute Error (MAE)

Direct Model Output (DMOs)
from NWP models
interpolated at HKO

Hong Kong Observatory Temperature Verification (Between 01 Apr 2020 and 30 Nov 2020 00Z)

OCF-D ECMWF (DMO) NCEP (DMO) ECMWF EPS MEAN (DMO) UKMO (DMO) JMA (DMO)

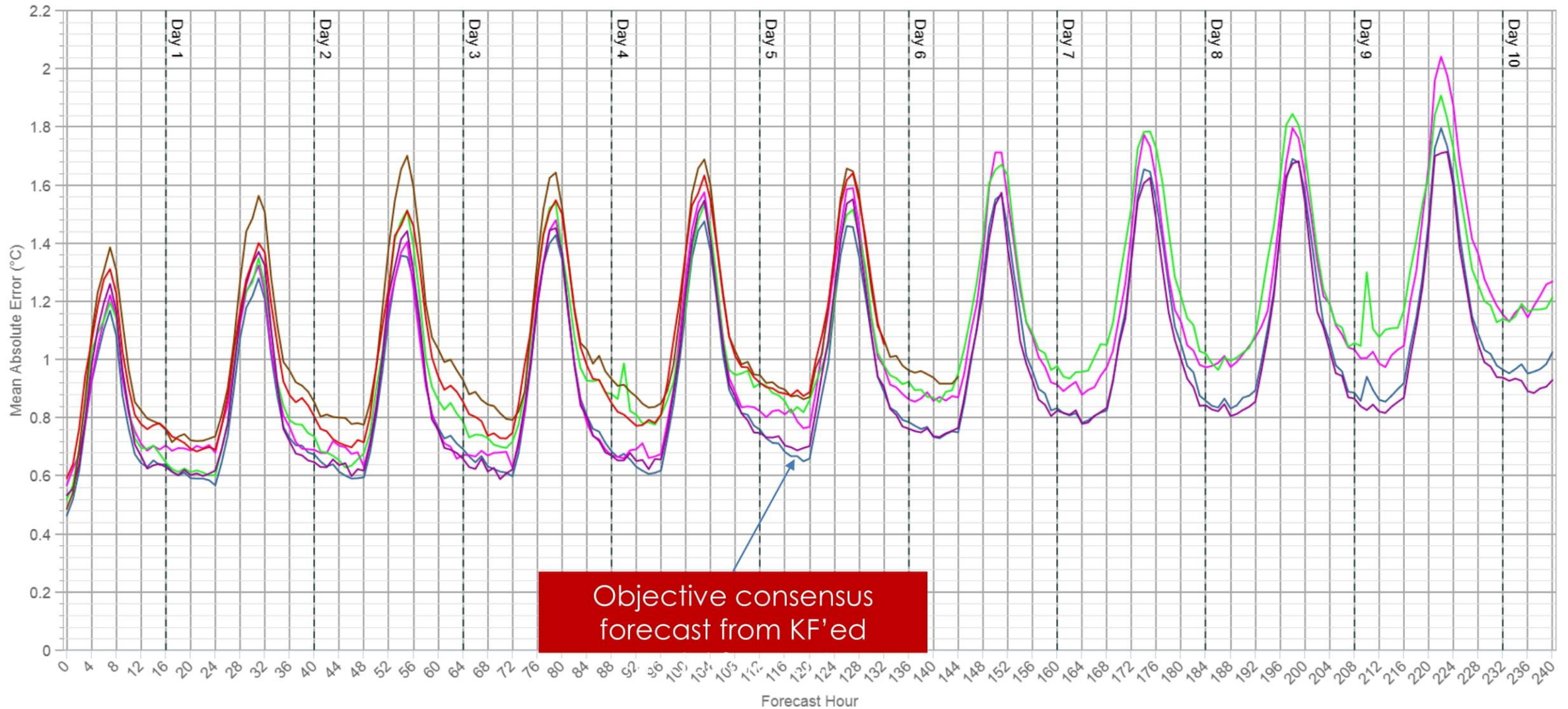


Mean Absolute Error (MAE)

Post-processed NWP model forecasts using Kalman filter

Hong Kong Observatory Temperature Verification (Between 01 Apr 2020 and 30 Nov 2020 00Z)

OCF-D ECMWF NCEP ECEPS MEAN UKMO JMA

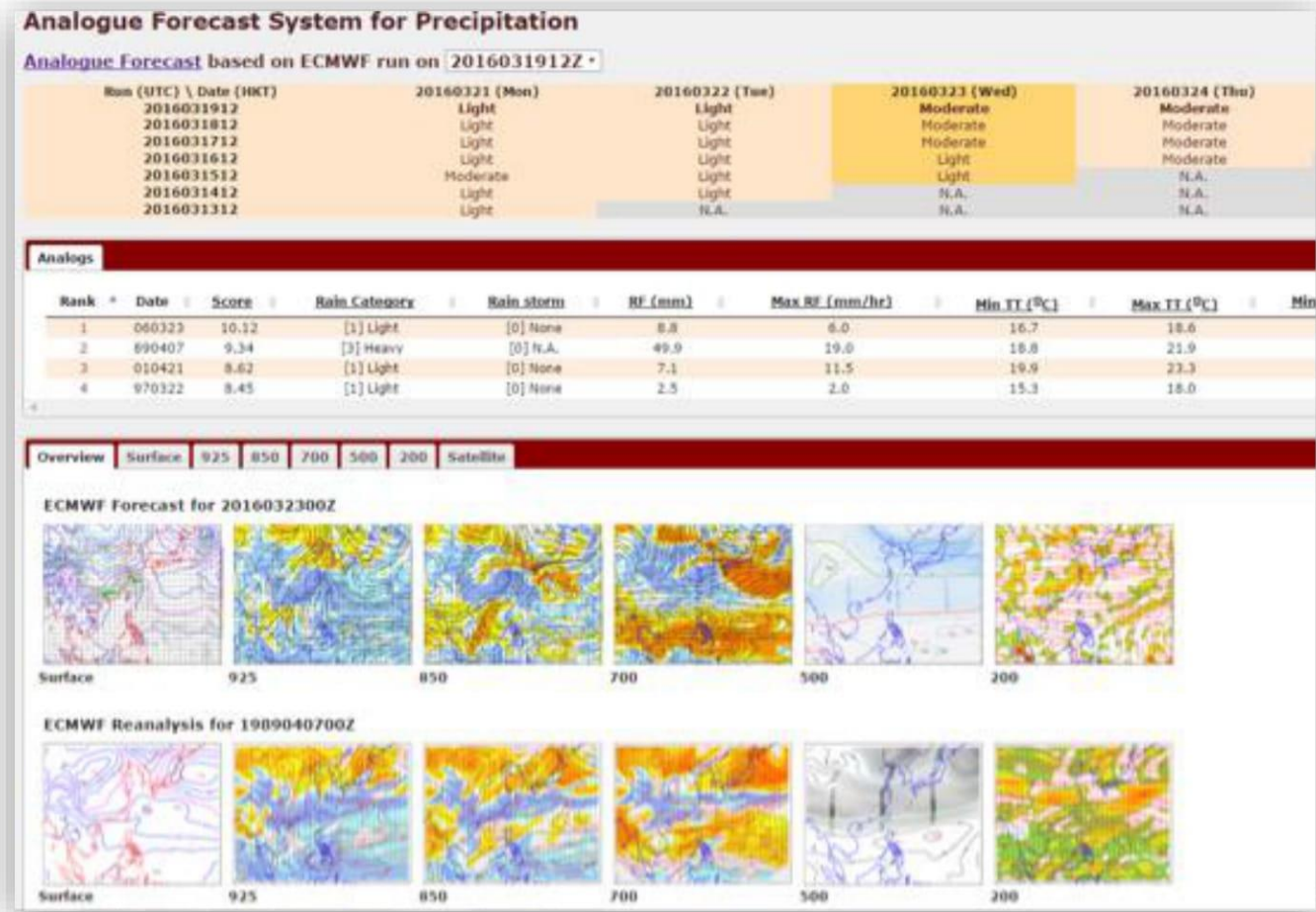


Model Post-processing for Heavy Rain Forecast

- Analogue Forecast System (AFS) for Precipitation
 - reference: <http://www.weather.gov.hk/publica/reprint/r1097.pdf>

– search for past cases based on ERA-Interim data (1979-2011) with similarities in synoptic pattern using geopotential heights and moisture, then rank the scores based on the near combination of

Rain Category	
Category	Rainfall (mm)
0 Nil	< 0.05
1 Light	>= 0.05 & < 10
2 Moderate	>= 10 & < 25
3 Heavy	>= 25 & < 50
4 Very Heavy	>= 50 & < 100
5 Torrential	>= 100 & < 200
6 Extreme	>= 200

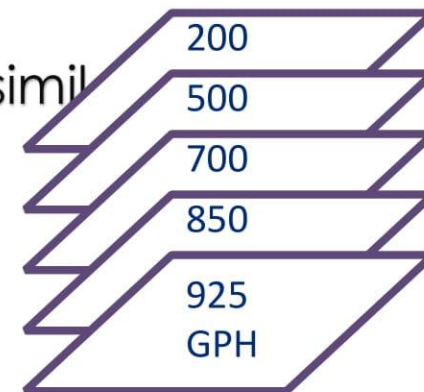


Methodology of Analogue Forecast System (AFS)

- Assumptions:
 - “History repeats itself”
 - a perfect prognosis by NWP model
- Features of AFS
 - automatically search good matching case(s) w.r.t. real-time NWP model forecast
 - specially tuned for heavy rain event
- Compare the similarities between (real-time) model forecast and historical cases
 - Similarity metrics:
 - Pattern matching of upper-air conditions (geopotential heights on selected levels)
 - Matching of synoptic pattern
 - Matching on spatial gradient of geopotential height fields
 - Water vapour
- Selection process
 - To determine the weighting of metrics and their relative importance
 - Need to handle non-linearity dependency

Example of similarity metric (1) - matching of synoptic patterns

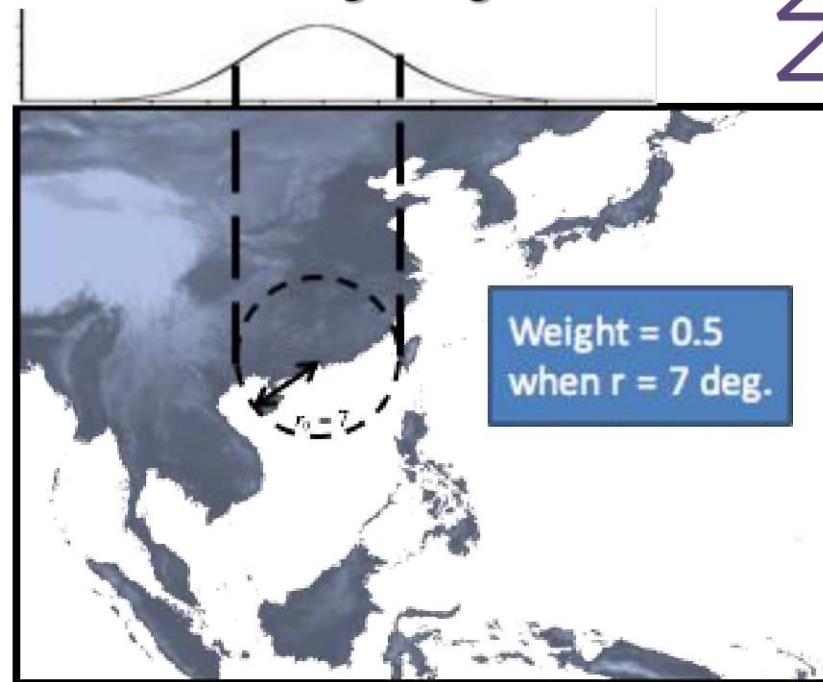
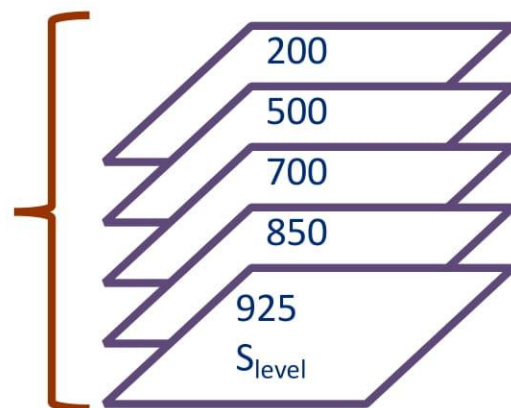
- Geopotential height (GPH) on 925, 850, 700, 500 and 200 hPa, compute similarity score using modified correlation coefficients (MCC)
 - Consider a larger weights following 2D Gaussian centred at Hong Kong



$$S_{resultant} = p_1 S_{925} + p_2 S_{850} + p_3 S_{700} + p_4 S_{500} + p_5 S_{200}$$

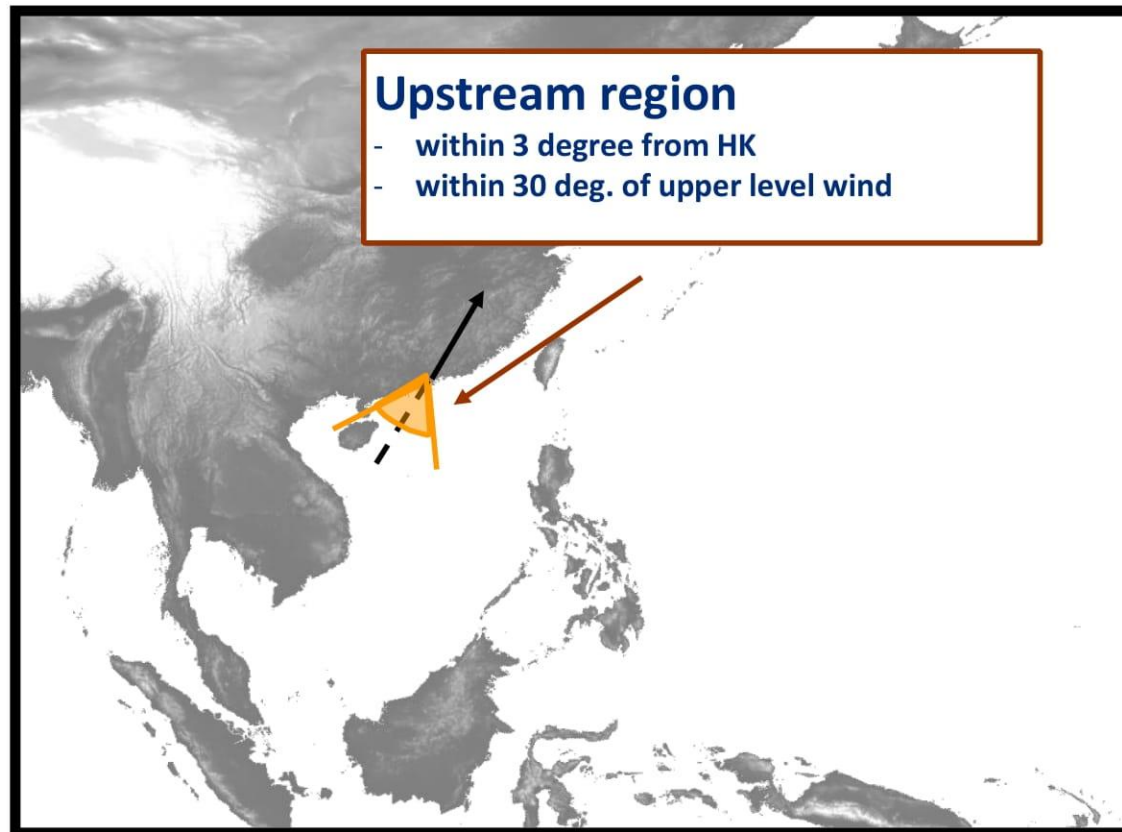
$$p_1 + p_2 + p_3 + p_4 + p_5 = 1$$

$S_{resultant}$



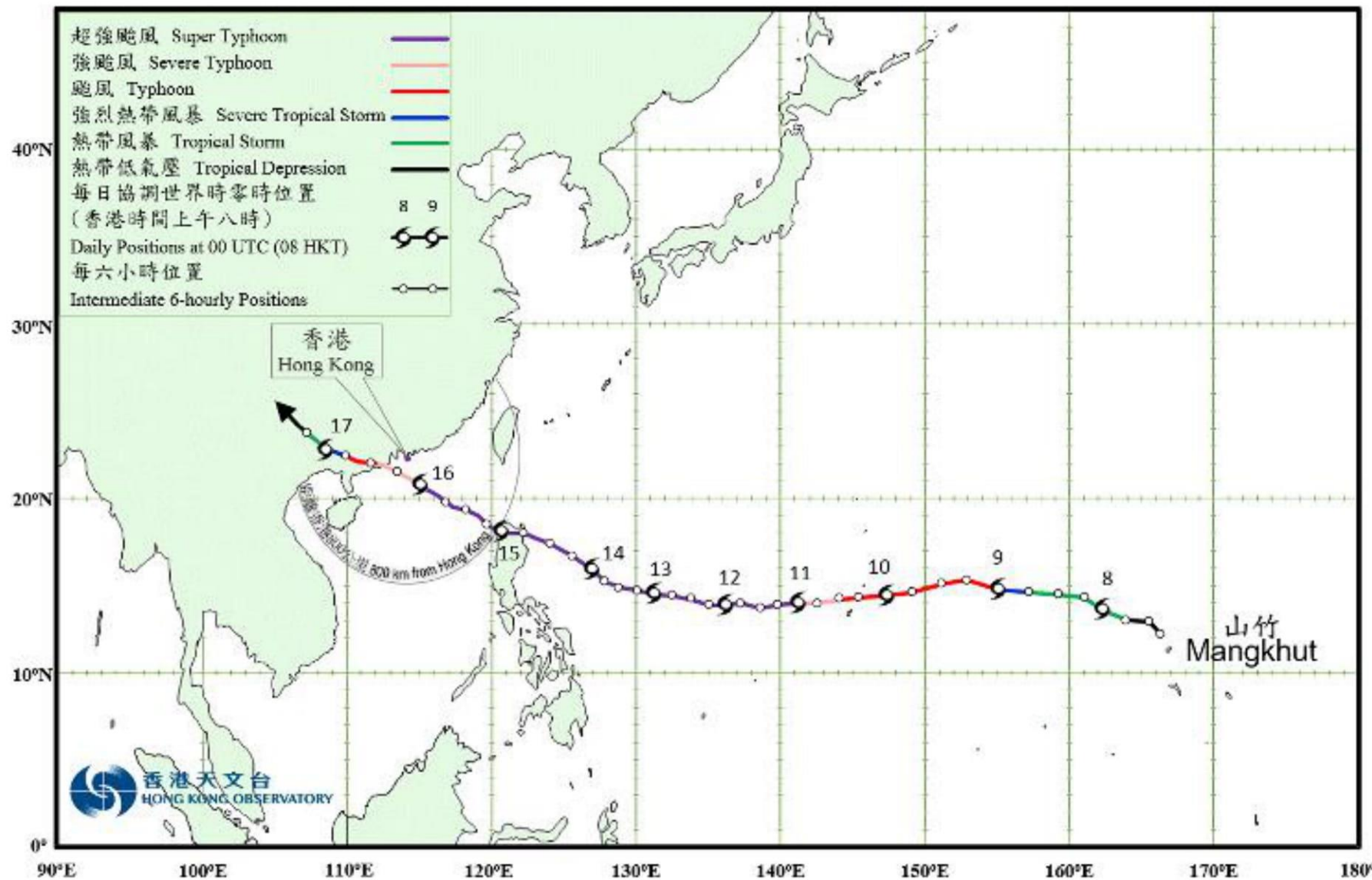
Example of similarity metrics (2) – Water vapour

- Similarity of water vapour on 850 hPa and 700 hPa



Mangkhut

Rainfall Forecast

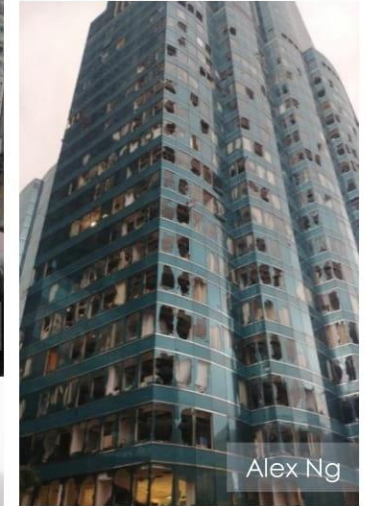


Hong Kong vs Super Typhoon **Mangkhut** (16 September 2018)

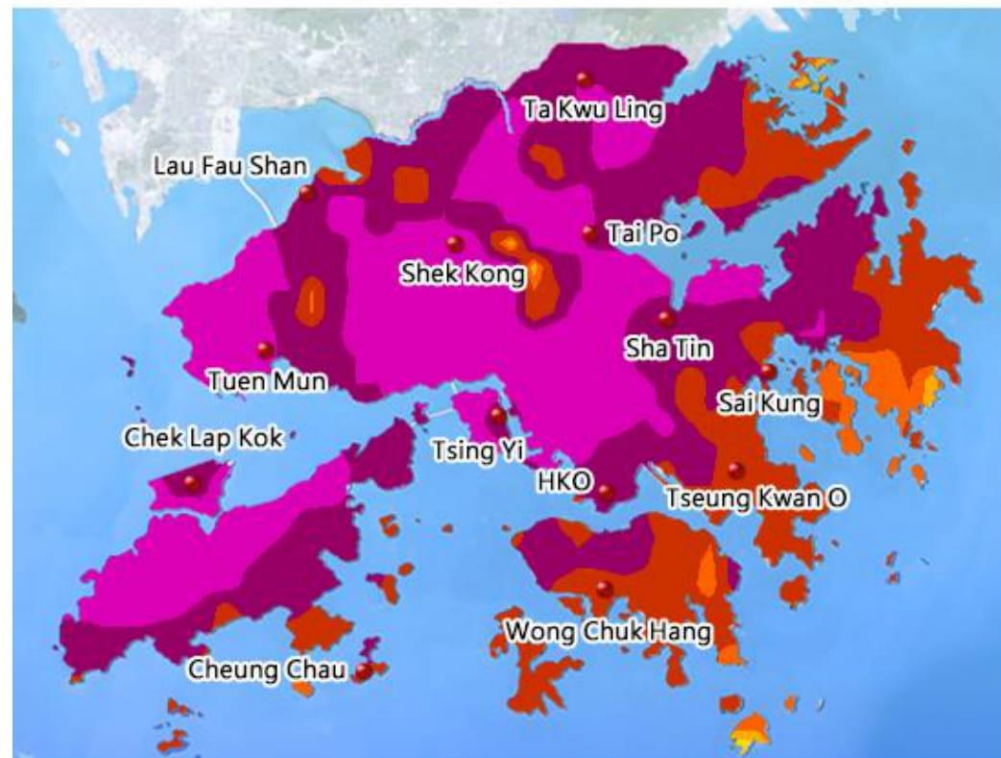
◆ Mangkhut was the sixteenth tropical cyclone necessitated the issuance of the No.10 Hurricane Signal (the highest typhoon signal) in Hong Kong since World War II. The No.10 Hurricane Signal was in force for 10 hours on 16 September 2018, the second longest duration on record and only shorter than the record long of 11 hours set by Typhoon York in 1999.

◆ Packing extreme high winds and record-breaking storm surge, Mangkhut ravaged the city and caused extensive damages to Hong Kong, including serious flooding in many coastal and low-lying areas, substantial damages of coastal structures and buildings, huge amount of fallen trees, many reports of smashed windows or glass curtain walls, and interruptions of water and power supply in some places. Traffic and transportation services were also seriously affected.

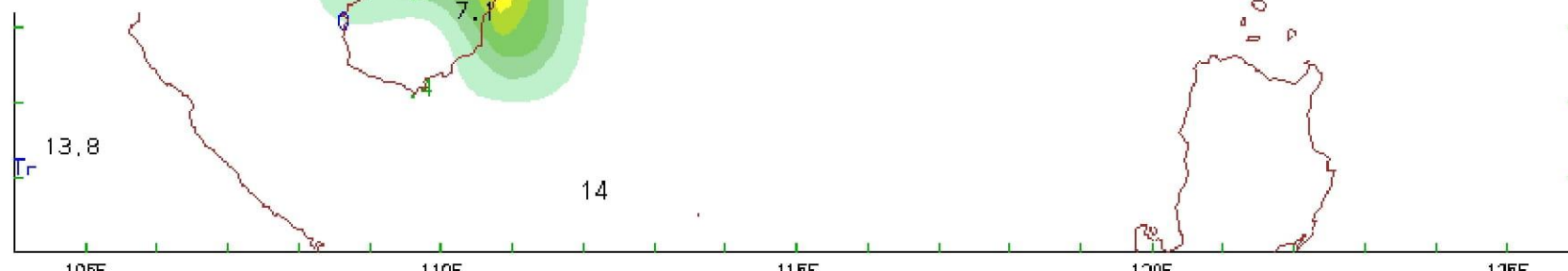
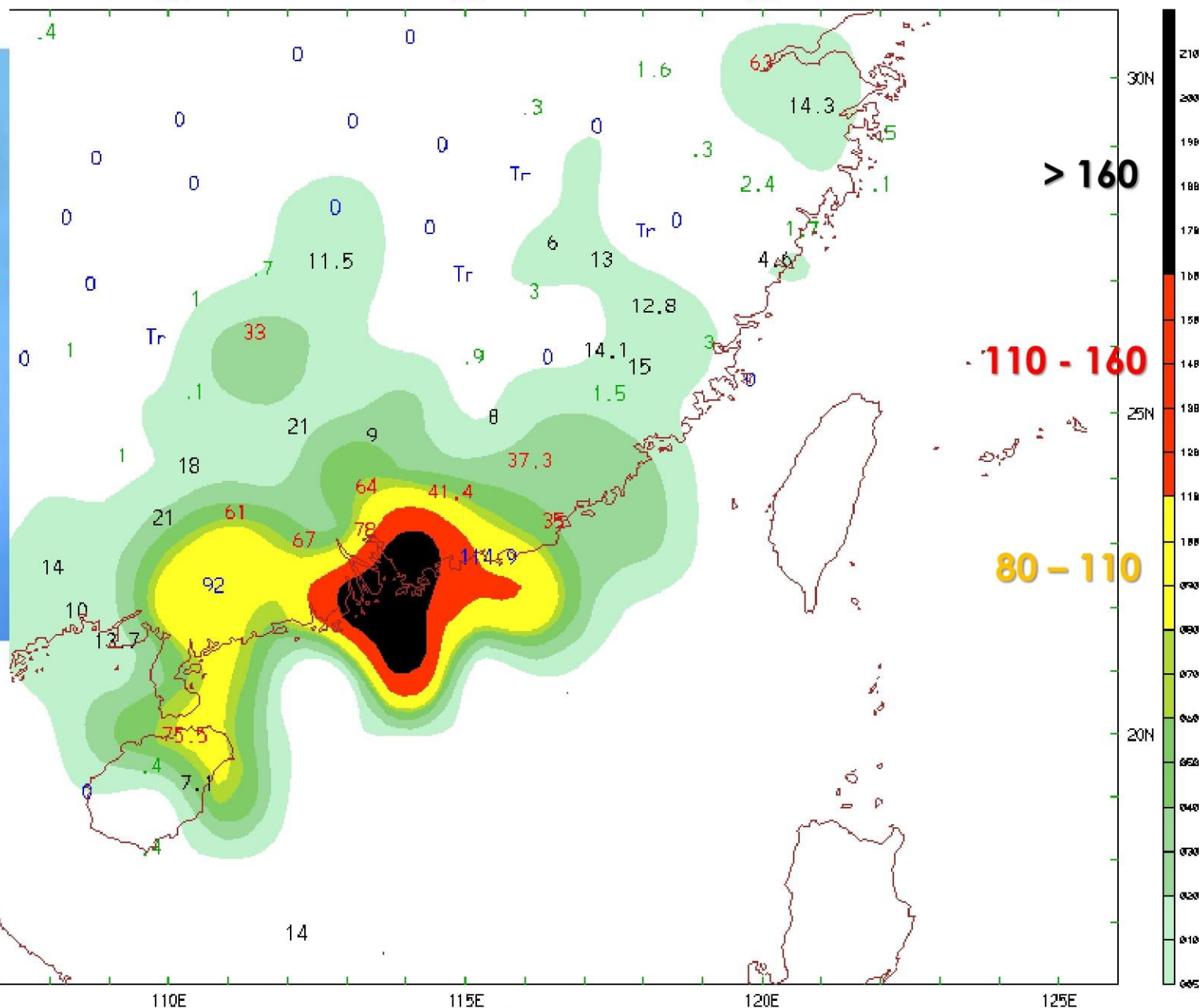
◆ While over 450 people were injured during the storm, there was no fatality on that day.



Total rainfall on **16-Sep-2018** (based on raingauges and radar data)



Daily rainfall in HK:
> 150 mm



14/00Z

Mangkhut (1822)

6-hourly Accumulated Rainfall Forecast

UTC	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
2018091406Z	0.0	0.1	0.1	0.5
2018091412Z	0.0	0.1	0.1	1.1
2018091418Z	0.1	0.1	0.0	0.7
2018091500Z	-	-	0.0	0.1
2018091506Z	-	-	142.6	0.0
2018091512Z	-	-	0.0	0.1
2018091518Z	-	-	1.5	0.0
2018091600Z	-	-	26.1	0.1
2018091606Z	-	-	44.5	8.6
2018091612Z	-	-	0.0	42.1
2018091618Z	-	-	210.5	35.2
2018091700Z	-	-	6.8	14.7
2018091706Z	-	-	3.3	11.9
2018091712Z	-	-	4.2	1.8
Base Time (UTC)	2018091318		2018091400	2018091400

Daily Rainfall Forecast

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180914	0.1*	0.3*	0.2*	2.0*
20180915	0.0*	0.0*	143.6	0.5
20180916	-	-	211.4	74.4
20180917	-	-	84.5*	40.1*

14/12Z

Mangkhut (1822)

6-hourly Accumulated Rainfall Forecast

UTC	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
2018091418Z	2.7	13.5	0.1	1.4
2018091500Z	0.0	12.1	0.0	0.0
2018091506Z	0.0	12.1	0.0	0.0
2018091512Z	0.0	12.1	0.0	0.0
2018091518Z	11.1	17.7	3.1	0.0
2018091600Z	14.7	19.5	36.8	0.5
2018091606Z	4.0	14.1	43.6	19.6
2018091612Z	-	-	17.3	49.4
2018091618Z	-	-	5.8	24.8
2018091700Z	-	-	7.3	12.9
2018091706Z	-	-	2.9	8.9
2018091712Z	-	-	7.7	5.0
2018091718Z	-	-	7.2	6.8
2018091800Z	-	-	1.6	8.9
Base Time (UTC)	2018091406		2018091412	2018091412

Daily Rainfall Forecast

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180914	1.8*	9.0*	0.1*	0.9*
20180915	8.3	52.6	2.1	0.5
20180916	22.4*	39.5*	102.6	86.0
20180917	-	-	24.6	39.5
20180918	-	-	4.0*	11.1*

15/00Z

Mangkhut (1822)

6-hourly Accumulated Rainfall Forecast

UTC	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
2018091506Z	0.0	32.9	0.0	0.0
2018091512Z	0.1	32.9	0.0	0.0
2018091518Z	1.0	33.3	1.5	0.0
2018091600Z	3.0	34.4	23.6	1.7
2018091606Z	17.7	41.7	66.1	33.1
2018091612Z	25.9	45.8	37.6	45.5
2018091618Z	0.0	32.8	9.5	20.5
2018091700Z	0.0	32.8	7.9	17.7
2018091706Z	-	-	4.7	9.1
2018091712Z	-	-	4.2	3.8
2018091718Z	-	-	7.6	8.7
2018091800Z	-	-	1.5	9.6
2018091806Z	-	-	1.6	7.9
2018091812Z	-	-	0.1	2.1
Base Time (UTC)	2018091500		2018091500	2018091500

Daily Rainfall Forecast

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180915	0.8*	88.0*	1.0*	0.0*
20180916	46.9	154.9	134.1	94.0
20180917	0.0*	43.7*	25.0	43.3
20180918	-	-	5.7*	22.5*

Analogue Forecast System for Precipitation

Analogue Forecast based on ECMWF run on **2018090912Z**

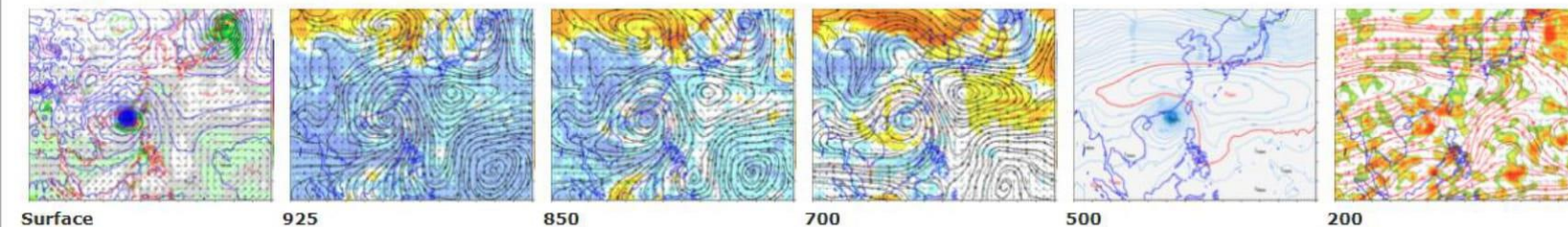
Run (UTC) \ Date (HKT)	20180911 (Tue)	20180912 (Wed)	20180913 (Thu)	20180914 (Fri)	20180915 (Sat)	20180916 (Sun)	20180917 (Mon)	20180918 (Tue)	20180919 (Wed)
2018090912	No Rain	Light	Light	No Rain	No Rain	Extreme	Heavy	Moderate	No Rain
2018090812	No Rain	No Rain	Light	No Rain	No Rain	Light	V. Heavy	Heavy	N.A.
2018090712	No Rain	No Rain	Heavy	Light	Light	No Rain	No Rain	N.A.	N.A.
2018090612	No Rain	Light	Heavy	Heavy	No Rain	No Rain	N.A.	N.A.	N.A.
2018090512	No Rain	Light	Moderate	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.
2018090412	No Rain	No Rain	Light	V. Heavy	N.A.	N.A.	N.A.	N.A.	N.A.
2018090312	No Rain	Light	Light	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090212	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090112	Moderate	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Analogs

Rank	Date	Score	Rain Category	Rain storm	RF (mm)	Max RF (mm/hr)	Min TT (°C)	Max TT (°C)	Min Vis (m)	Mean Vis (m)	Mean Cld (%)	Sunshine (hr)
1	990916	4.54	[6] Extreme	[2] Red	222.1	73.3	24.7	28.4	500	3962	100	0.0

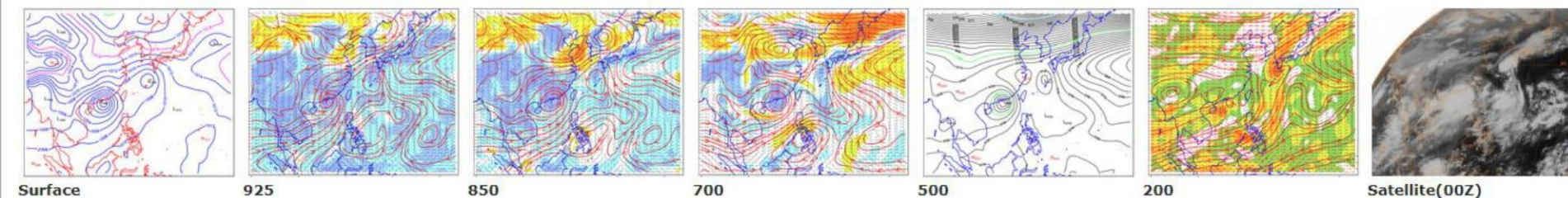
Overview Surface 925 850 700 500 200 Satellite

ECMWF Forecast for 2018091600Z



Typhoon York (1999)

ECMWF Reanalysis for 1999091600Z



Analogue Forecast System for Precipitation

Analogue Forecast based on ECMWF run on **2018091212Z**

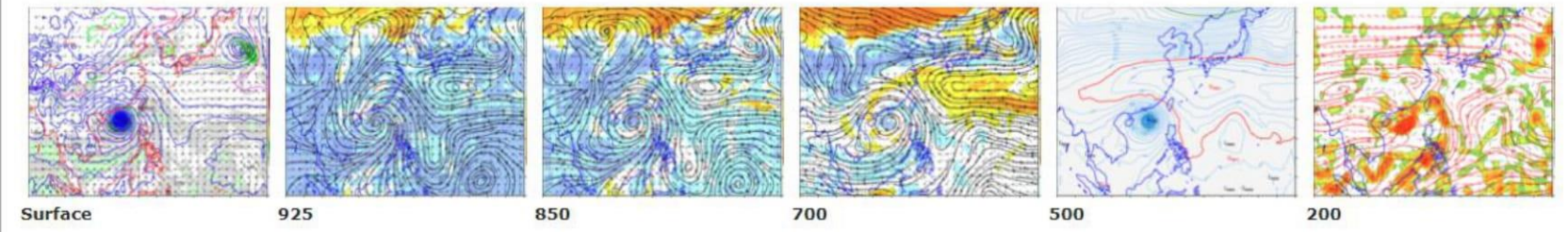
Run (UTC) \ Date (HKT)	20180914 (Fri)	20180915 (Sat)	20180916 (Sun)	20180917 (Mon)	20180918 (Tue)	20180919 (Wed)	20180920 (Thu)	20180921 (Fri)	20180922 (Sat)
2018091212	No Rain	No Rain	V. Heavy	Heavy	Heavy	Light	Moderate	No Rain	Light
2018091112	No Rain	No Rain	Extreme	Heavy	Light	Light	No Rain	No Rain	N.A.
2018091012	No Rain	No Rain	V. Heavy	Heavy	Heavy	No Rain	Light	N.A.	N.A.
2018090912	No Rain	No Rain	Extreme	Heavy	Moderate	No Rain	N.A.	N.A.	N.A.
2018090812	No Rain	No Rain	Light	V. Heavy	Heavy	N.A.	N.A.	N.A.	N.A.
2018090712	Light	Light	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.
2018090612	Heavy	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090512	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090412	V. Heavy	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Analogs

Rank	Date	Score	Rain Category	Rain storm	RF (mm)	Max RF (mm/hr)	Min TT (°C)	Max TT (°C)	Min Vis (m)	Mean Vis (m)	Mean Cld (%)	Sunshine (hr)
1	080806	4.46	[4] V. Heavy	[0] None	70.1	23.5	24.2	28.8	2000	9479	99	0.1

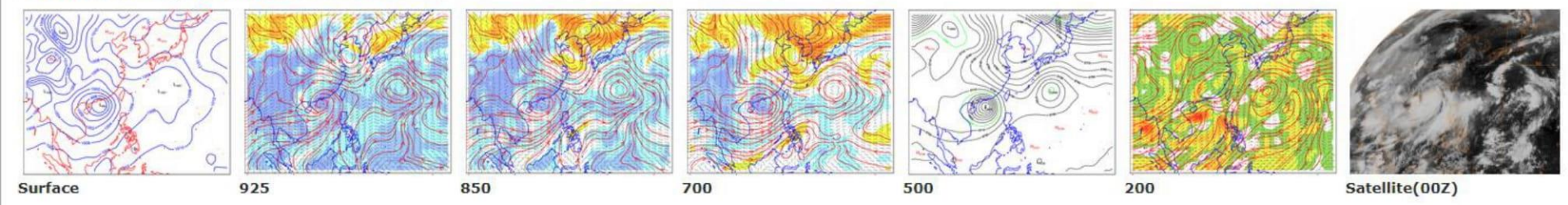
Overview Surface 925 850 700 500 200 Satellite

ECMWF Forecast for 2018091600Z



STS Kammuri (2008)

ECMWF Reanalysis for 2008080600Z



Analogue Forecast System for Precipitation

Analogue Forecast based on ECMWF run on **2018091412Z**

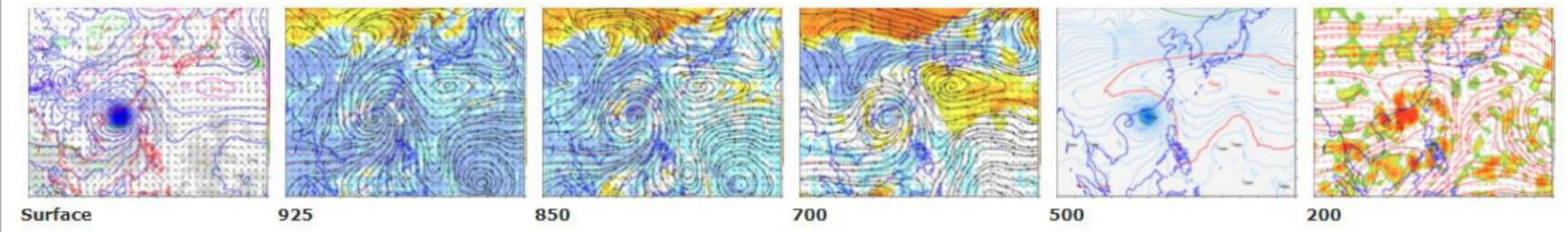
Run (UTC) \ Date (HKT)	20180916 (Sun)	20180917 (Mon)	20180918 (Tue)	20180919 (Wed)	20180920 (Thu)	20180921 (Fri)	20180922 (Sat)	20180923 (Sun)	20180924 (Mon)
2018091412	Extreme	Moderate	Moderate	No Rain	Light	No Rain	No Rain	No Rain	No Rain
2018091312	V. Heavy	Heavy	Heavy	No Rain	Moderate	No Rain	Light	Light	N.A.
2018091212	V. Heavy	Heavy	Heavy	Light	Moderate	No Rain	Light	N.A.	N.A.
2018091112	Extreme	Heavy	Light	Light	No Rain	No Rain	N.A.	N.A.	N.A.
2018091012	V. Heavy	Heavy	Heavy	No Rain	Light	N.A.	N.A.	N.A.	N.A.
2018090912	Extreme	Heavy	Moderate	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.
2018090812	Light	V. Heavy	Heavy	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090712	No Rain	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
2018090612	No Rain	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Analogs

Rank	Date	Score	Rain Category	Rain storm	RF (mm)	Max RF (mm/hr)	Min TT (°C)	Max TT (°C)	Min Vis (m)	Mean Vis (m)	Mean Cld (%)	Sunshine (hr)
1	990916	10.22	[6] Extreme	[2] Red	222.1	73.3	24.7	28.4	500	3962	100	0.0

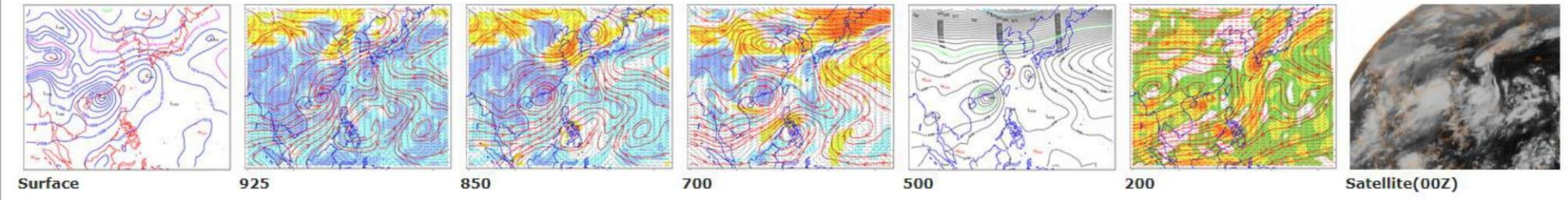
Overview Surface 925 850 700 500 200 Satellite

ECMWF Forecast for 2018091600Z



Typhoon York
(1999)

ECMWF Reanalysis for 1999091600Z



- Thank you very much -

Q & A