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AI-BASED NOWCASTING IN EXTREME WEATHER PREDICTION

WMO AI for Nowcasting Pilot Project (AINPP) Workshop

Session 3 – AI based Nowcasting

25 September 2025

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Outline

1. Evolution of Deep Learning Precipitation Nowcast Models in HKO Nowcasting System SWIRLS

2. Regional Convection / Precipitation Nowcast Supports using Deep Learning Models

3. Ensemble nowcast and AI-based guidance for rainstorm / extreme precipitation

4. Way forward on AI nowcast support

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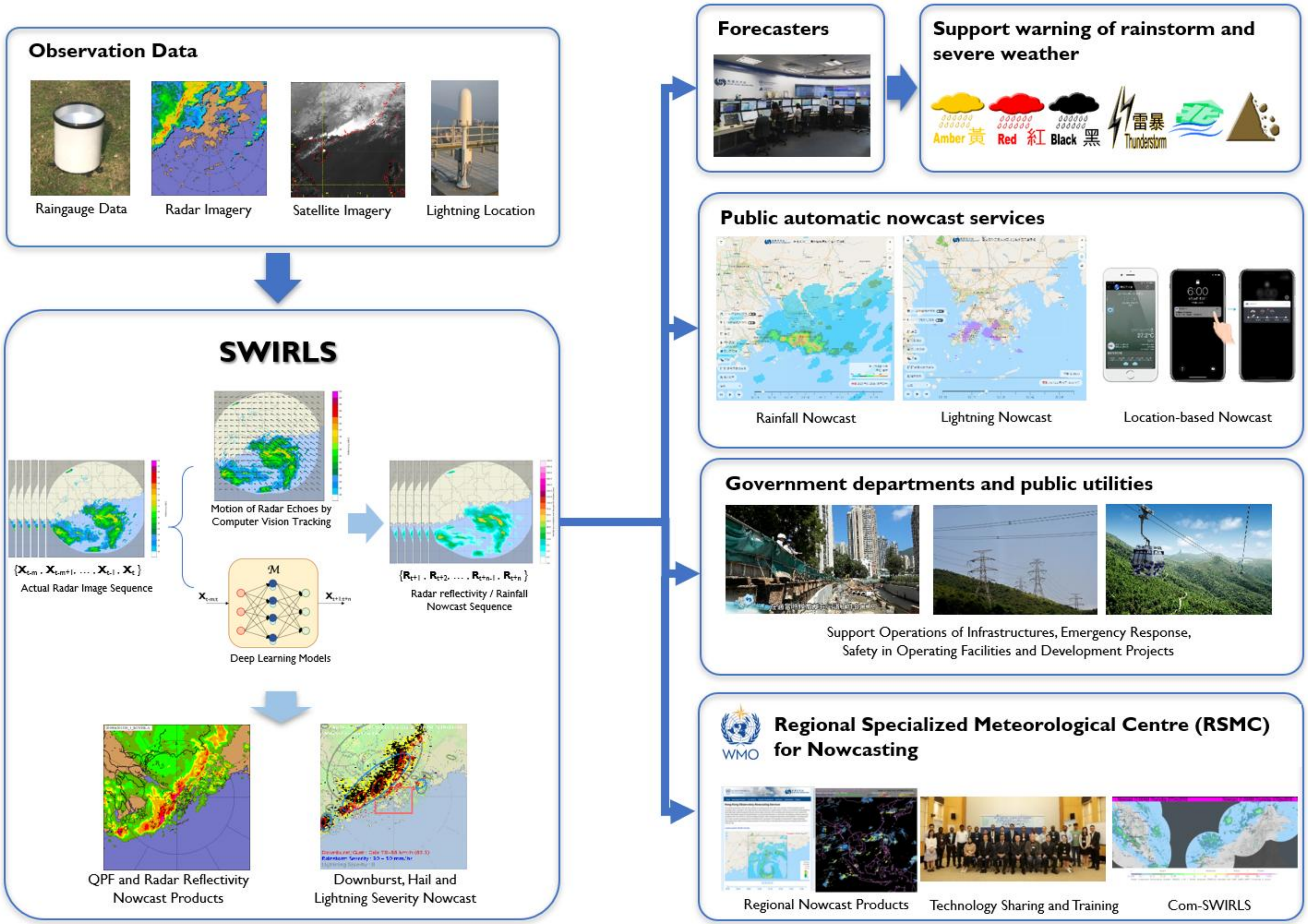
SWIRLS

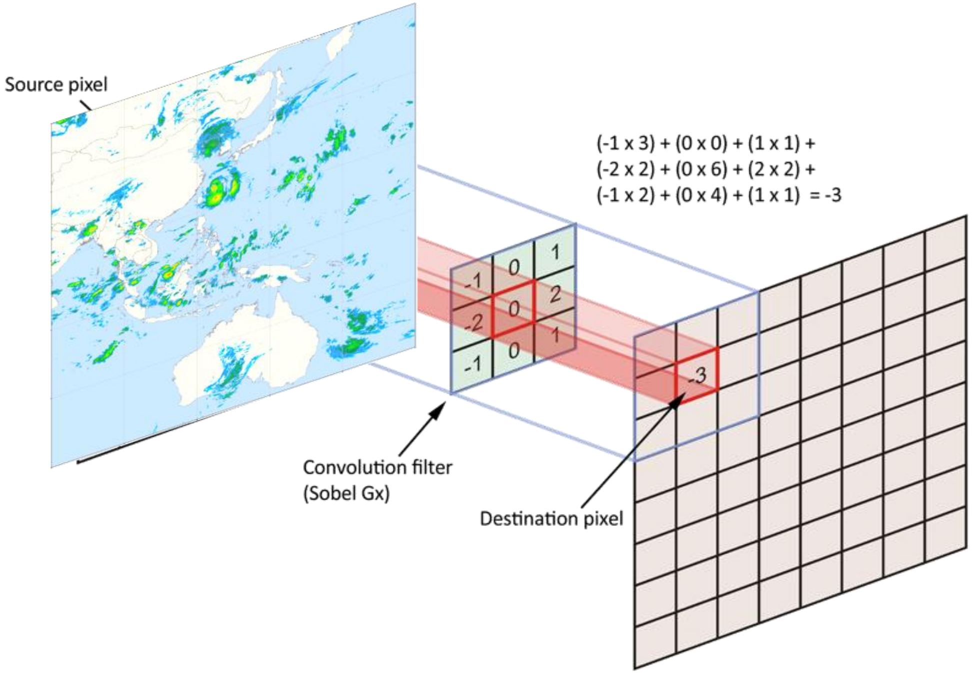
Short-range Warning of Intense Rainstorms in Localized Systems

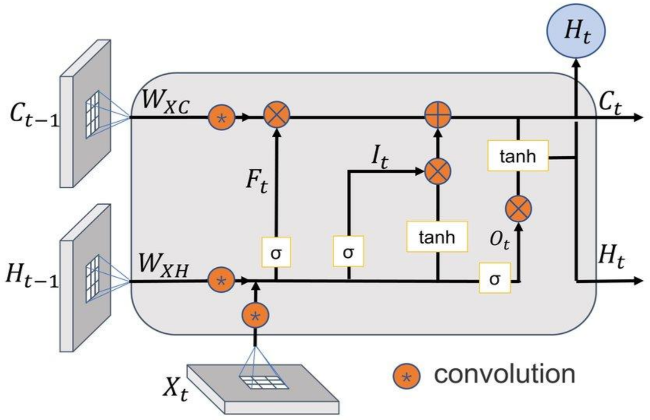


Encoding-forecasting ConvLSTM network

X. Shi, Z. Chen, H. Wang, D.Y. Yeung, W.K. Wong and W.C. Woo. Convolutional LSTM network: A machine learning approach for precipitation nowcasting. NIPS 2015.

https://arxiv.org/abs/1506.04214





$$\mathbf{I}_t = \sigma(\mathbf{W}_{xi} * \mathbf{X}_t + \mathbf{W}_{hi} * \mathbf{H}_{t-1} + \mathbf{W}_{ci} \odot \mathbf{C}_{t-1} + b_i)$$

$$\mathbf{F}_t = \sigma(\mathbf{W}_{xf} * \mathbf{X}_t + \mathbf{W}_{hf} * \mathbf{H}_{t-1} + \mathbf{W}_{cf} \odot \mathbf{C}_{t-1} + b_f)$$

$$\mathbf{C}_t = \mathbf{F}_t \odot \mathbf{C}_{t-1} + \mathbf{I}_t \odot \tau_h(\mathbf{W}_{xc} * \mathbf{X}_t + \mathbf{W}_{hc} * \mathbf{H}_{t-1} + b_c)$$

$$\mathbf{O}_t = \sigma(\mathbf{W}_{xo} * \mathbf{X}_t + \mathbf{W}_{ho} * \mathbf{H}_{t-1} + \mathbf{W}_{co} \odot \mathbf{C}_t + b_o)$$

$$\mathbf{H}_t = \mathbf{O}_t \odot \tau_o(\mathbf{C}_t)$$

Convolution operator

- Good at feature extraction
- More intuitive model architecture

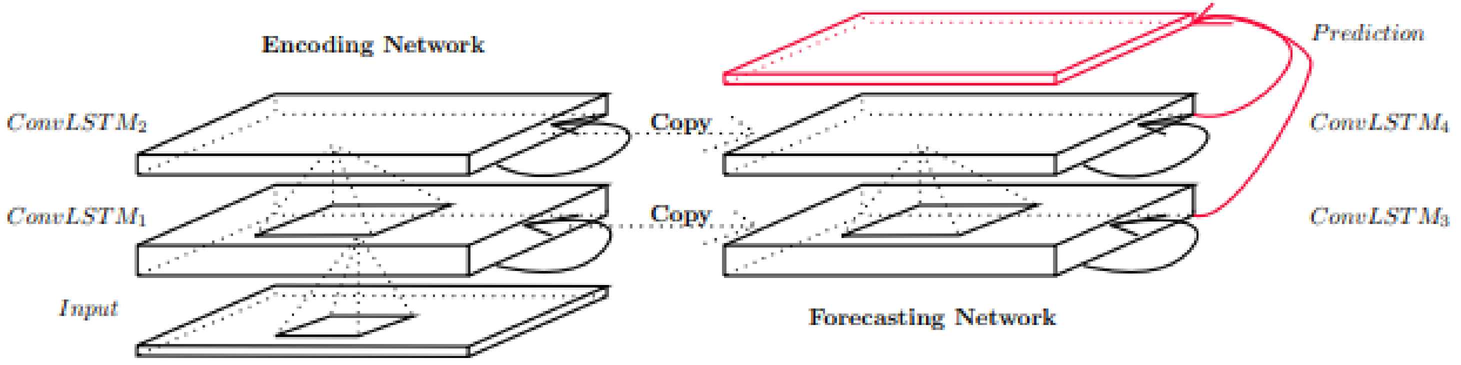


Figure 3: Encoding-forecasting ConvLSTM network for precipitation nowcasting

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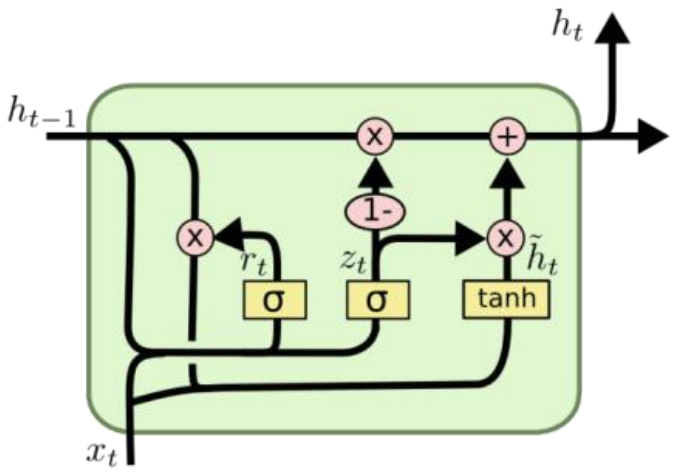
Xingjian Shi, Zhihan Gao, Leonard Lausen, Hao Wang, Dit-Yan Yeung, Wai-kin Wong, and Wang-chun Woo, 2017: Deep learning for precipitation nowcasting: A benchmark and a new model. https://arxiv.org/pdf/1706.03458.pdf

Trajectory Gated Recurrence Unit (TrajGRU)

TrajGRU replaces LSTM, introduces "Trajectory" and adopts weighted error function

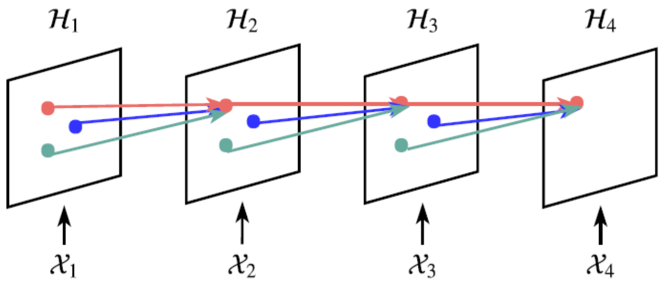
"HKO-7" dataset available to community to promote development of AI in nowcasting

GRU (Gated Recurrent Unit) includes *reset gate* and *update gate*, similar to LSTM but more efficient.

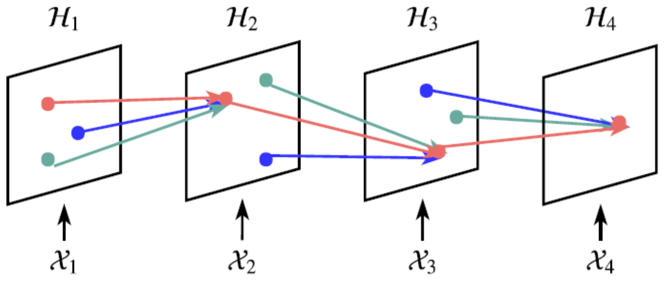


Trajectory:

Recurrent connections are dynamically determined



(a) ConvRNN: Links are fixed over time/location.



(b) TrajRNN: Links are dynamically determined.

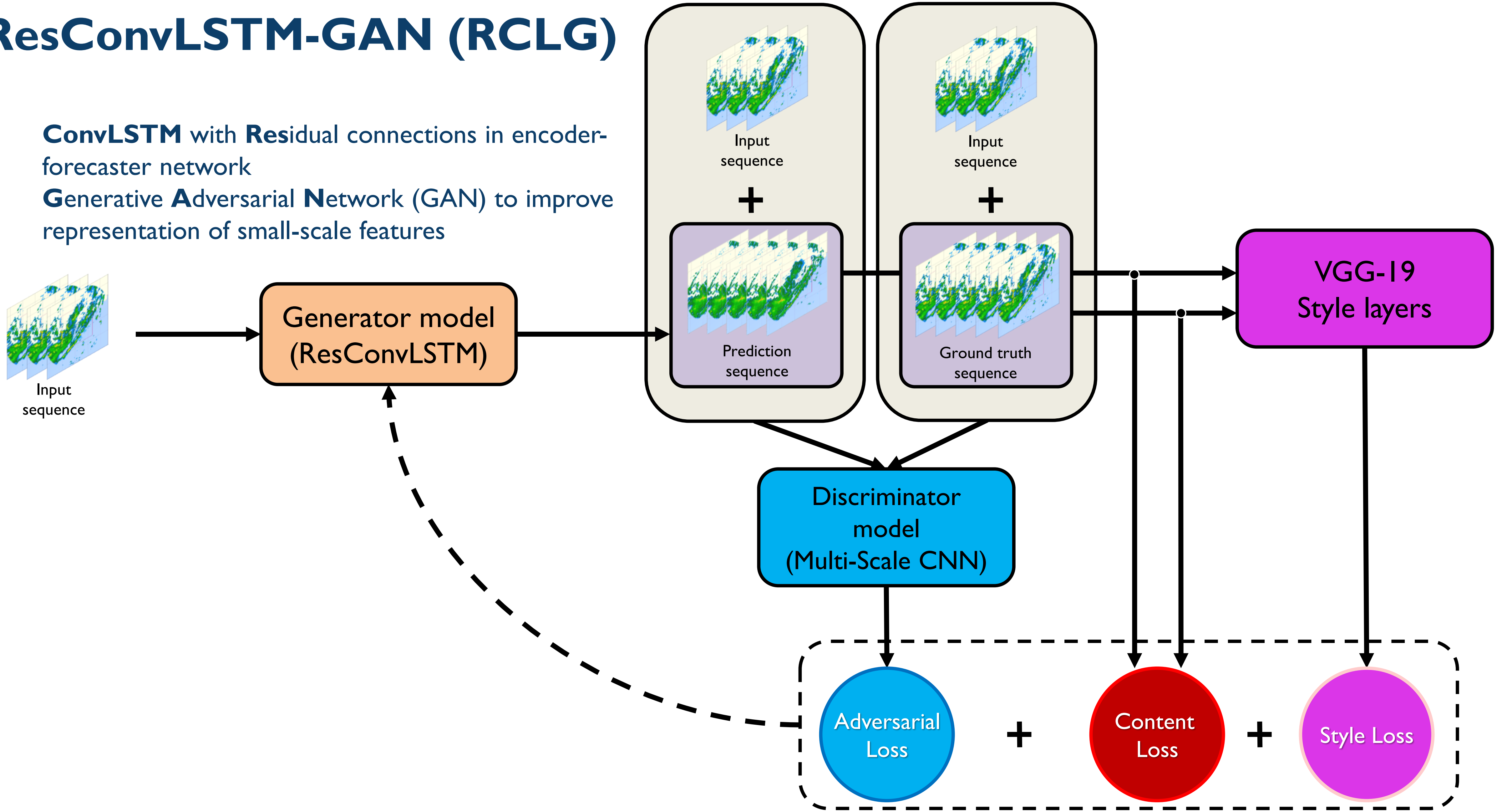
Weighted Error:

optimize performance in heavy rain

$w(x)$ to each pixel according to its rainfall intensity x: $w(x) = \begin{cases} 1, & x < 2 \\ 2, & 2 \leq x < 5 \\ 5, & 5 \leq x < 10 \\ 10, & 10 \leq x < 30 \\ 30, & x \geq 30 \end{cases}$. Also, the masked pixels have weight 0. The resulting B-MSE and B-MAE scores are computed as B-MSE $= \frac{1}{N}\sum_{n=1}^{N}\sum_{i=1}^{480}\sum_{j=1}^{480} w_{n,i,j}(x_{n,i,j} - \hat{x}_{n,i,j})^2$ and B-MAE $= \frac{1}{N}\sum_{n=1}^{N}\sum_{i=1}^{480}\sum_{j=1}^{480} w_{n,i,j}|x_{n,i,j} - \hat{x}_{n,i,j}|$, where N is the total number of frames and $w_{n,i,j}$ is the weight corresponding to the (i,j)th pixel in the nth frame. For the conventional MSE and MAE measures, we simply set all the weights to 1 except the masked points.

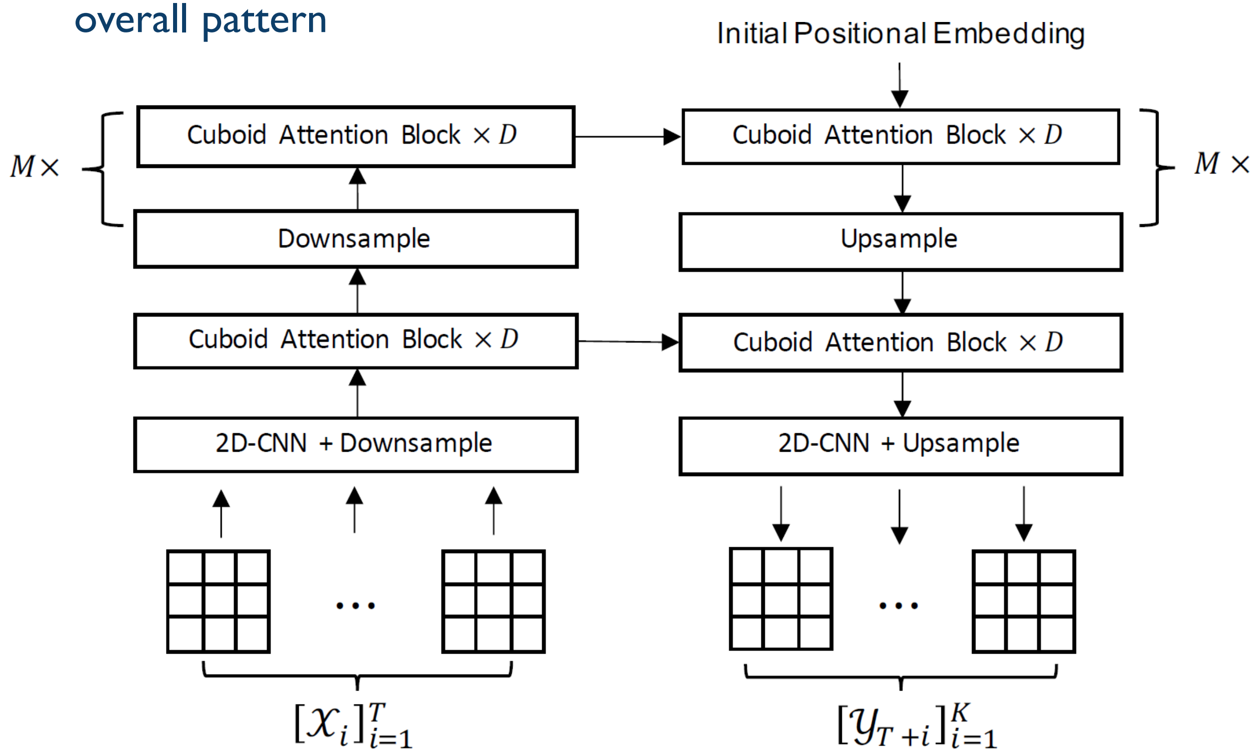
ResConvLSTM-GAN (RCLG)

- **ConvLSTM** with **Res**idual connections in encoder-forecaster network
- **G**enerative **A**dversarial **N**etwork (GAN) to improve representation of small-scale features

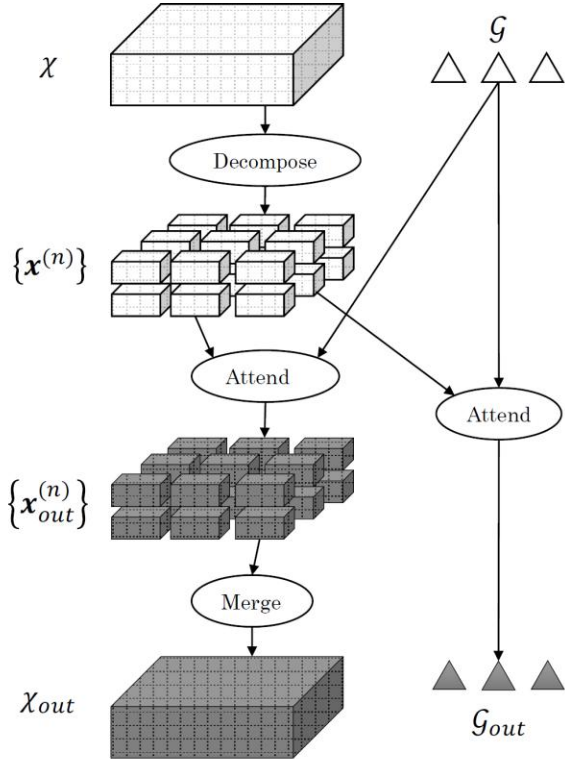


Earthformer

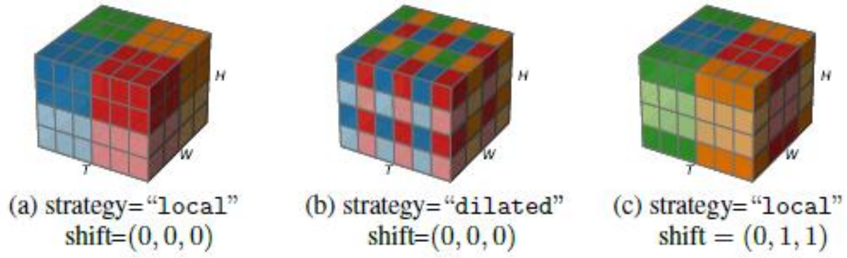
- **Space-time Transformer** model based on Cuboid Attention
- Spatiotemporal data are divided into non-overlapping cuboids, and **self-attention** is applied locally within each cuboid
- **Global vectors** are used to connect the cuboids for capturing the overall pattern



https://arxiv.org/abs/2207.05833



Cuboid attention layer with global vectors



Cuboid decomposition strategies in attention layer

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Enhanced feature preservation using Fourier Amplitude and Correlation Loss (FACL)

Ref: https://arxiv.org/abs/2410.23159

DFT of image X of height M and width N

$$F_{pq} = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} X_{mn} e^{-i2\pi\left(\frac{mp}{M}+\frac{nq}{N}\right)}$$

Fourier frequencies

$$\mathrm{FAL}(X, \hat{X}) = \frac{1}{MN} \sum_{p=0}^{M-1} \sum_{q=0}^{N-1} \left(|F|_{pq} - |\hat{F}|_{pq}\right)^2$$

Image structure

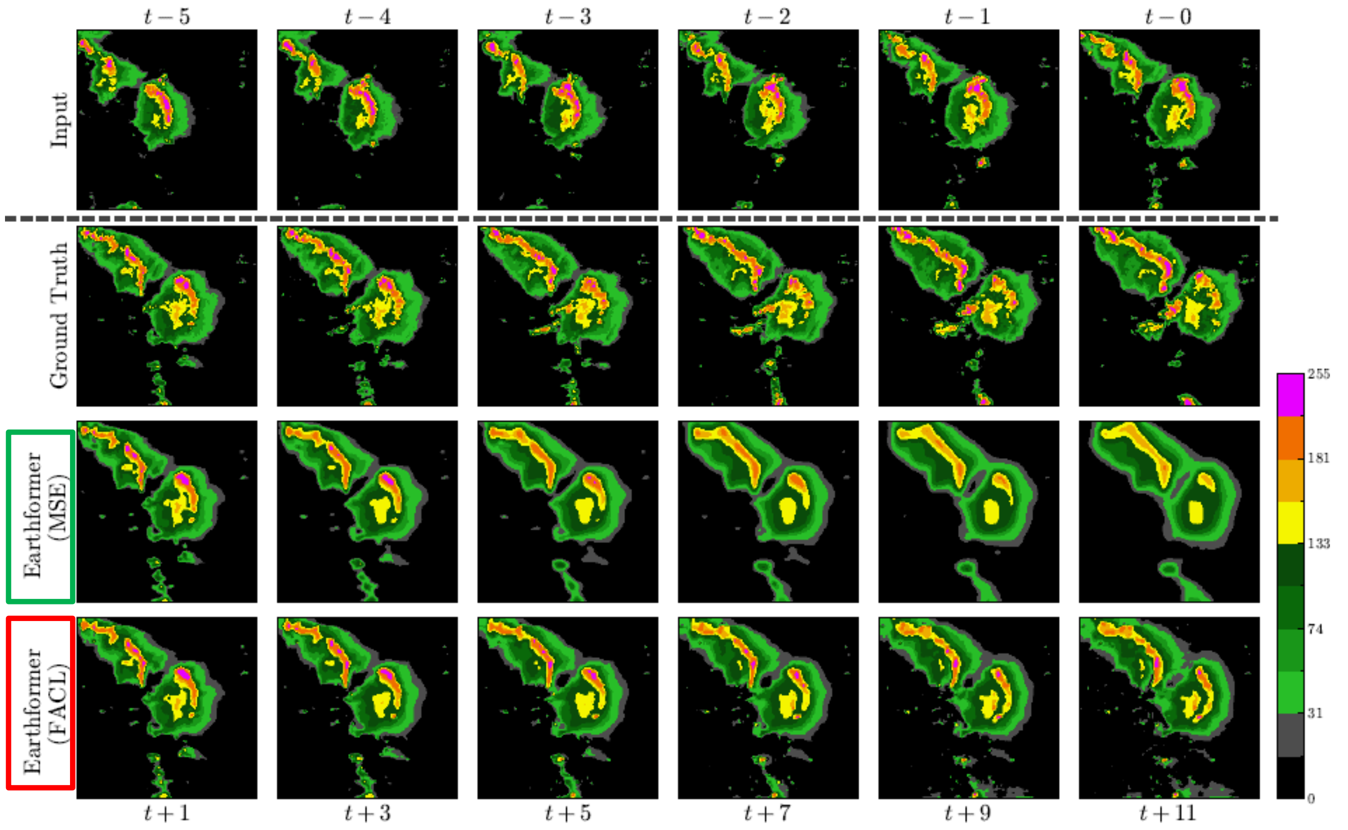
$$\mathrm{FCL}(X, \hat{X}) = 1 - \frac{\frac{1}{2}\sum[F\hat{F}^* + \hat{F}F^*]}{\sqrt{\sum|F|^2 \sum|\hat{F}|^2}}$$

A new metric **RHD (Regional Histogram Divergence)** to improve over traditional L1 loss, L2 loss and FSS (Fraction Skill Score) to measure patch-wise similarly between two spatiotemporal patterns

$$\mathrm{FSS} = 1 - \frac{\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}(F_{i,j} - O_{i,j})^2}{\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}F_{i,j}^2 + \sum_{i=1}^{N_x}\sum_{j=1}^{N_y}O_{i,j}^2}$$

$$\mathrm{RHD} = \frac{1}{N_x N_y}\sum_{i=1}^{N_x}\sum_{j=1}^{N_y} D_{\mathrm{KL}}(O'_{i,j}||F'_{i,j}) = \frac{1}{N_x N_y}\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\sum_{x\in\mathcal{X}} O'_{i,j}(x)\log\frac{O'_{i,j}(x)}{F'_{i,j}(x)}$$

Predicted frames of the Earthformer models trained with **MSE** and **FACL**

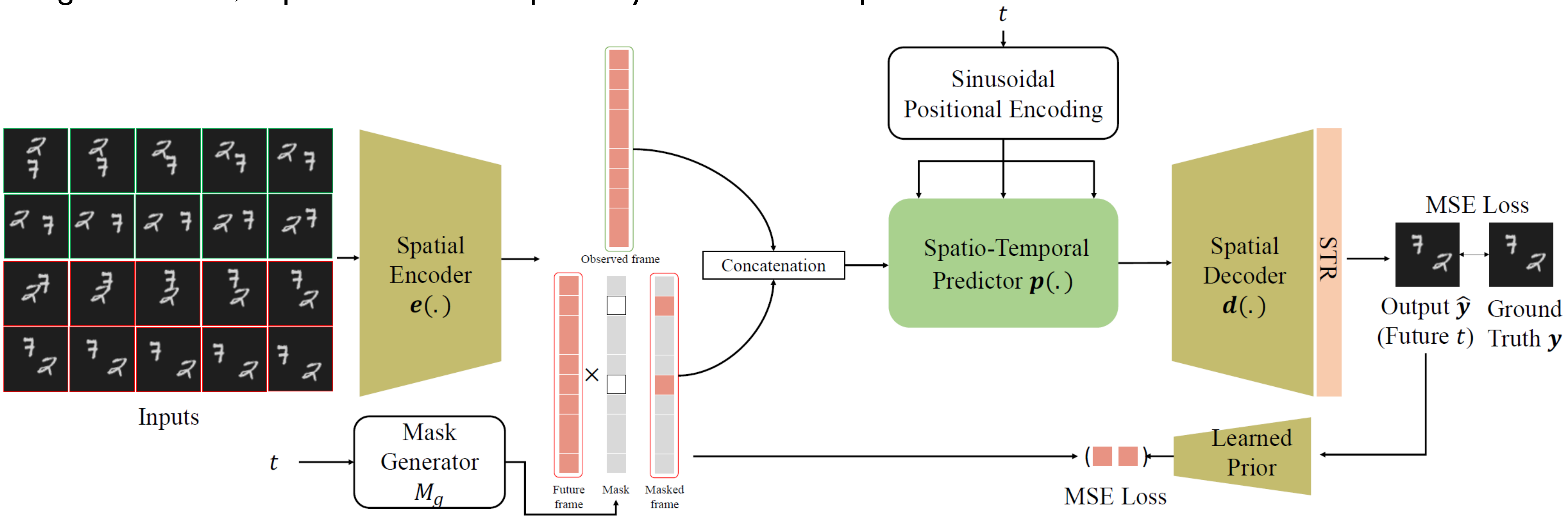


F' and O' is predicted and observed discrete probability distribution respectively

➔ **RHD penalizes more on "blur" pattern**

Implicit Stacked Autoregressive Model for Video Prediction (IAM4VP)

A stacked autoregressive method applied in an implicit video prediction model resulting in improved performance at longer lead time, as predictions are sequentially stacked in the queue

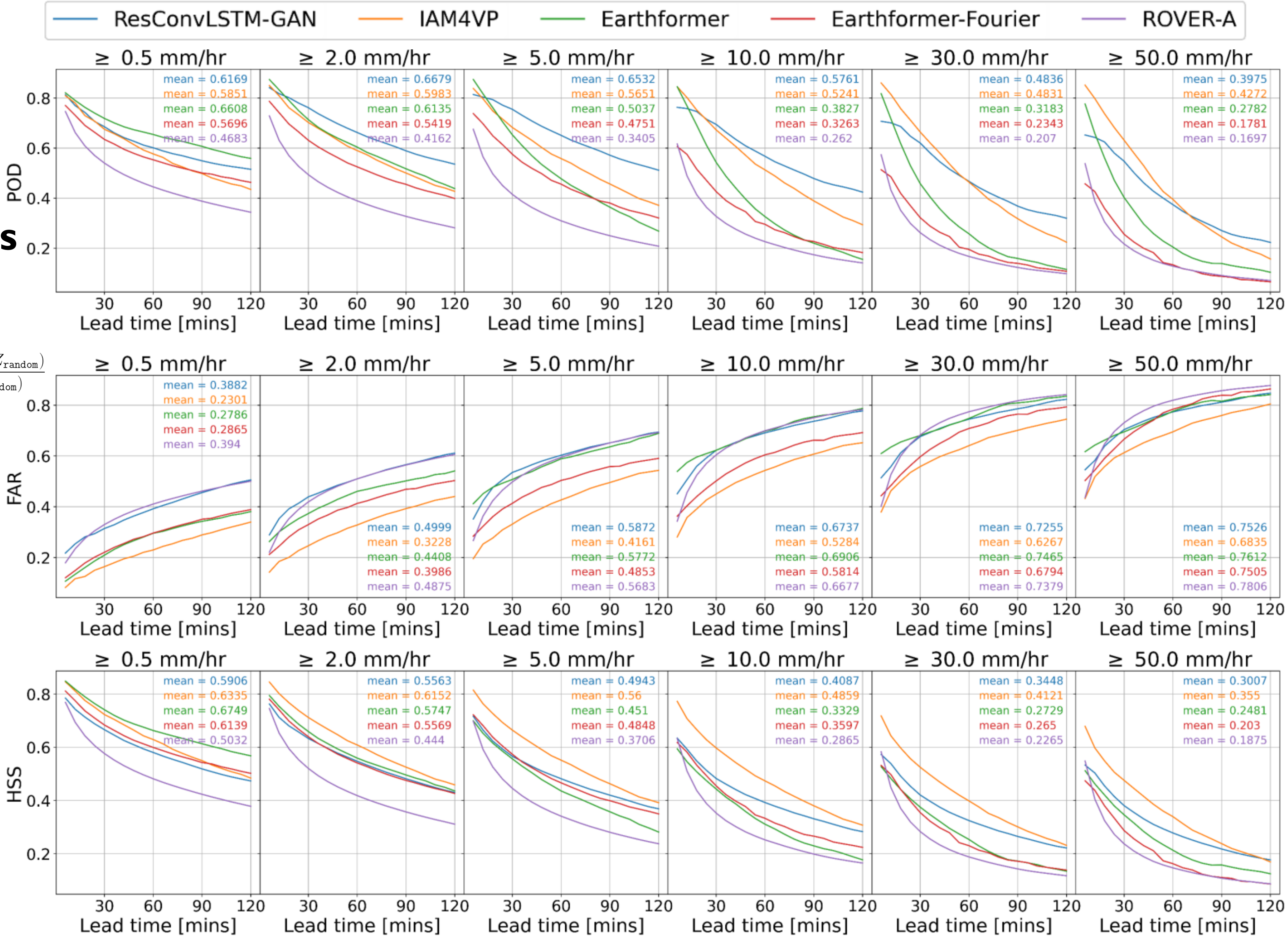


https://arxiv.org/abs/2303.07849

Verification Metrics

POD, FAR, HSS

$$HSS = \frac{POC - POC_{\text{random}}}{1 - POC_{\text{random}}} = \frac{(H+Z) - (H_{\text{random}} + Z_{\text{random}})}{N - (H_{\text{random}} + Z_{\text{random}})}$$



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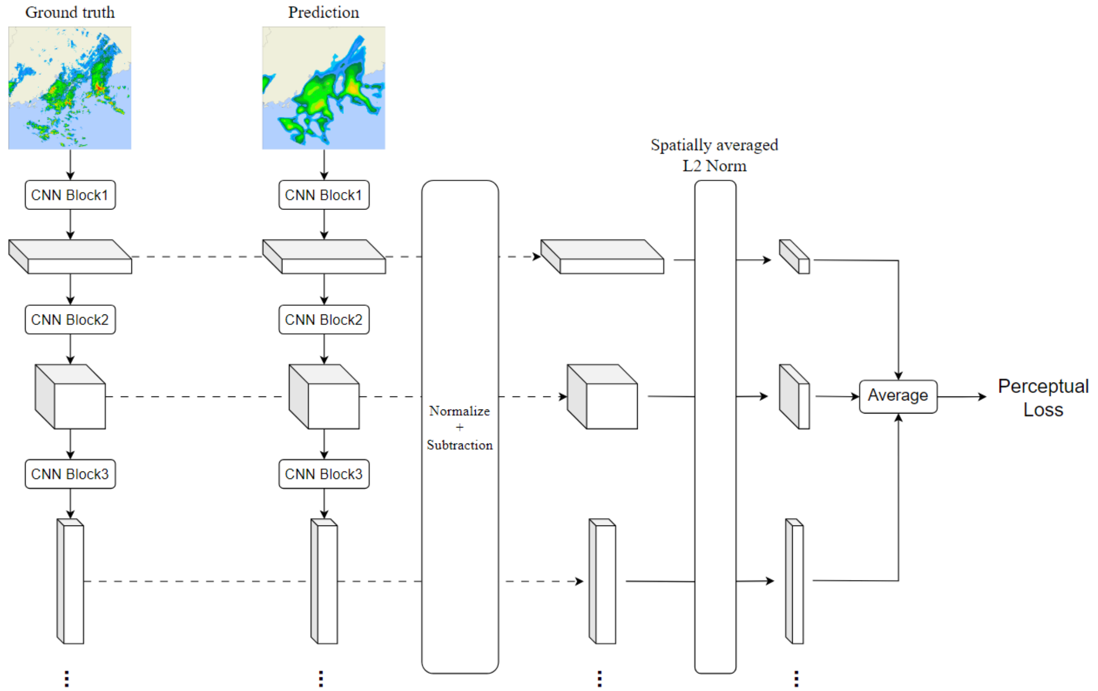
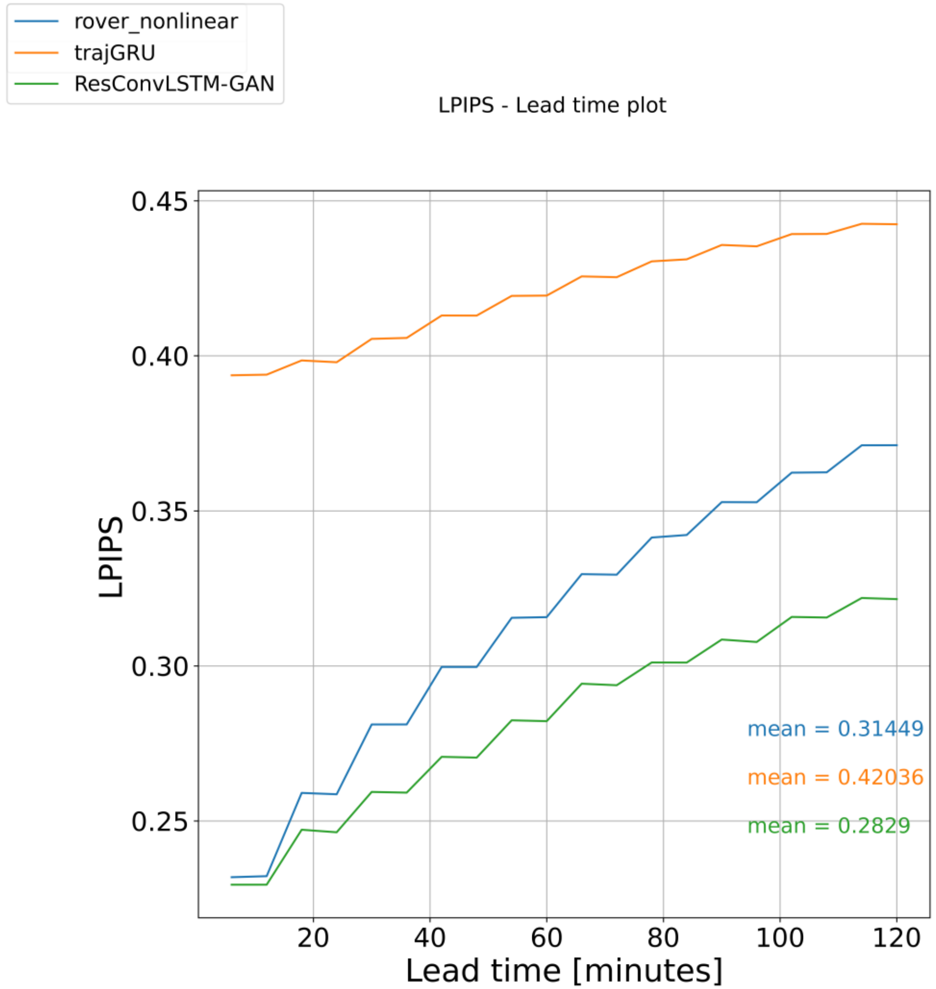
Verification Metric - Perceptual Similarity

- Learned Perceptual Patch Similarity (LPIPS) metric
  - A Neural Network(NN)-based metric to match human perception, lower the better
  - Measure the difference of activations in a pre-defined NN between 2 images
  - Pre-defined NN: AlexNet

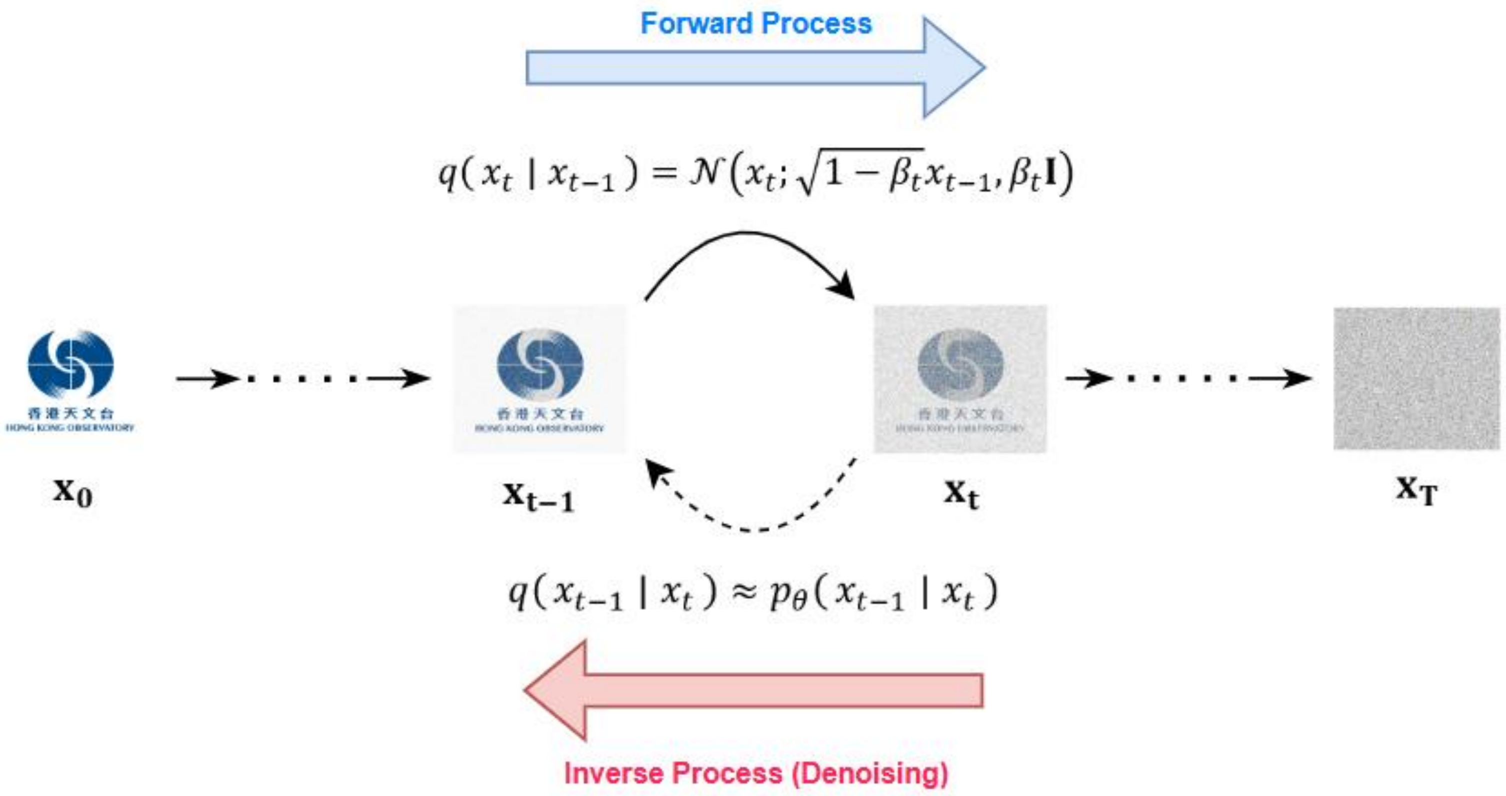


- More realistic features generated in ResConvLSTM-GAN nowcast compared to TrajGRU and optical flow extrapolation



Denoising Diffusion Probabilistic Model (DDPM)

- Diffusion Model consists of two processes: Forward Process (noising) and Inverse Process (denoising)
- To capture the data distribution by training a neural network to undo a Markov noising process that gradually distorts the data



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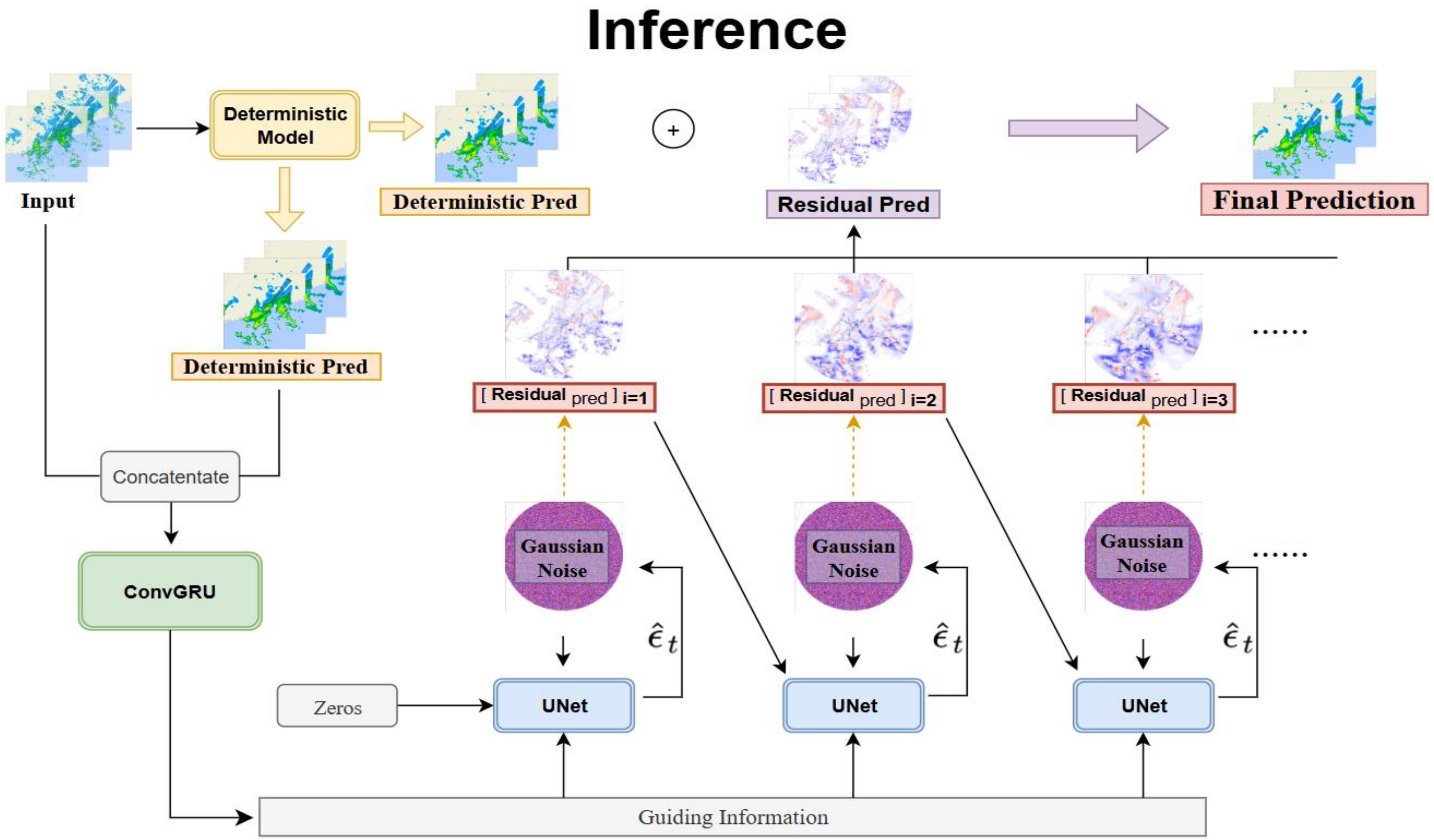
DDPM implementation

$$y = \hat{y}(x) + r$$

target *blurry prediction* *residual*

- "Deterministic model": any model that makes "blurry prediction" such as CNN or Transformer based models

- Diffusion model in learning to generate the residual based on past radar frames and forecast from the "Deterministic model" and able to generate more realistic forecast



In the denoising process, different outputs could be generated and thus producing an ensemble prediction

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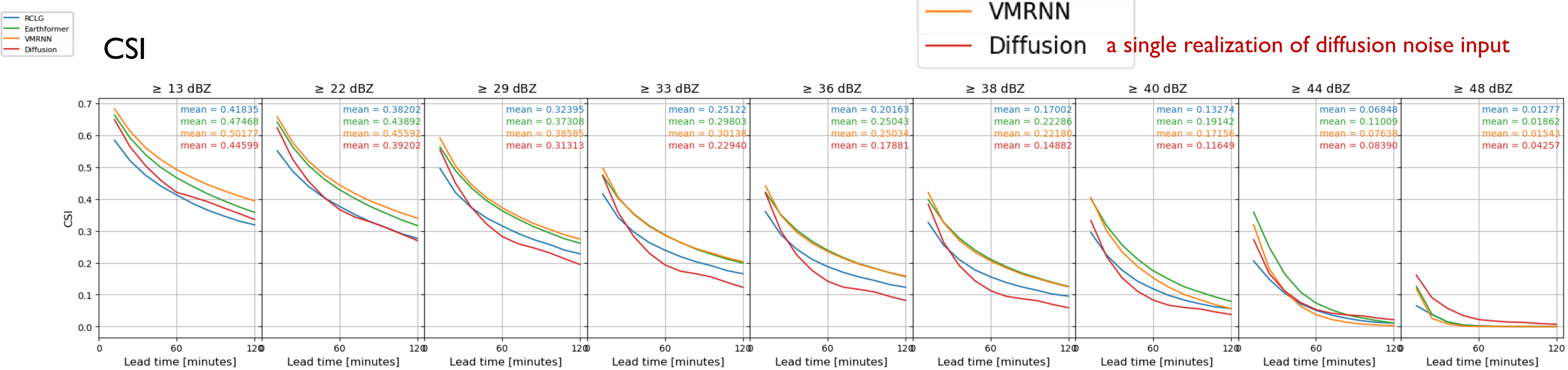
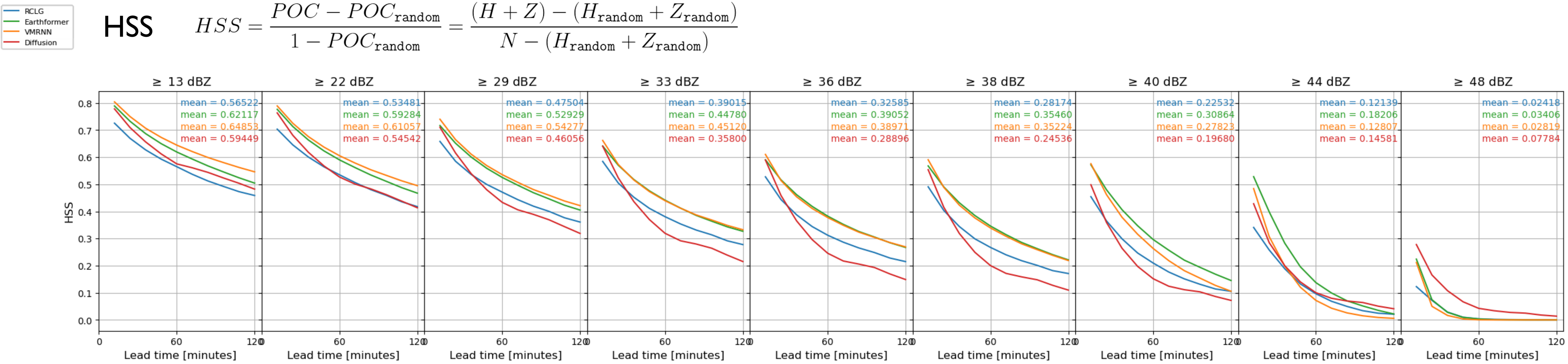
RCLG
Earthformer
VMRNN
Diffusion a single realization of diffusion noise input

CSI

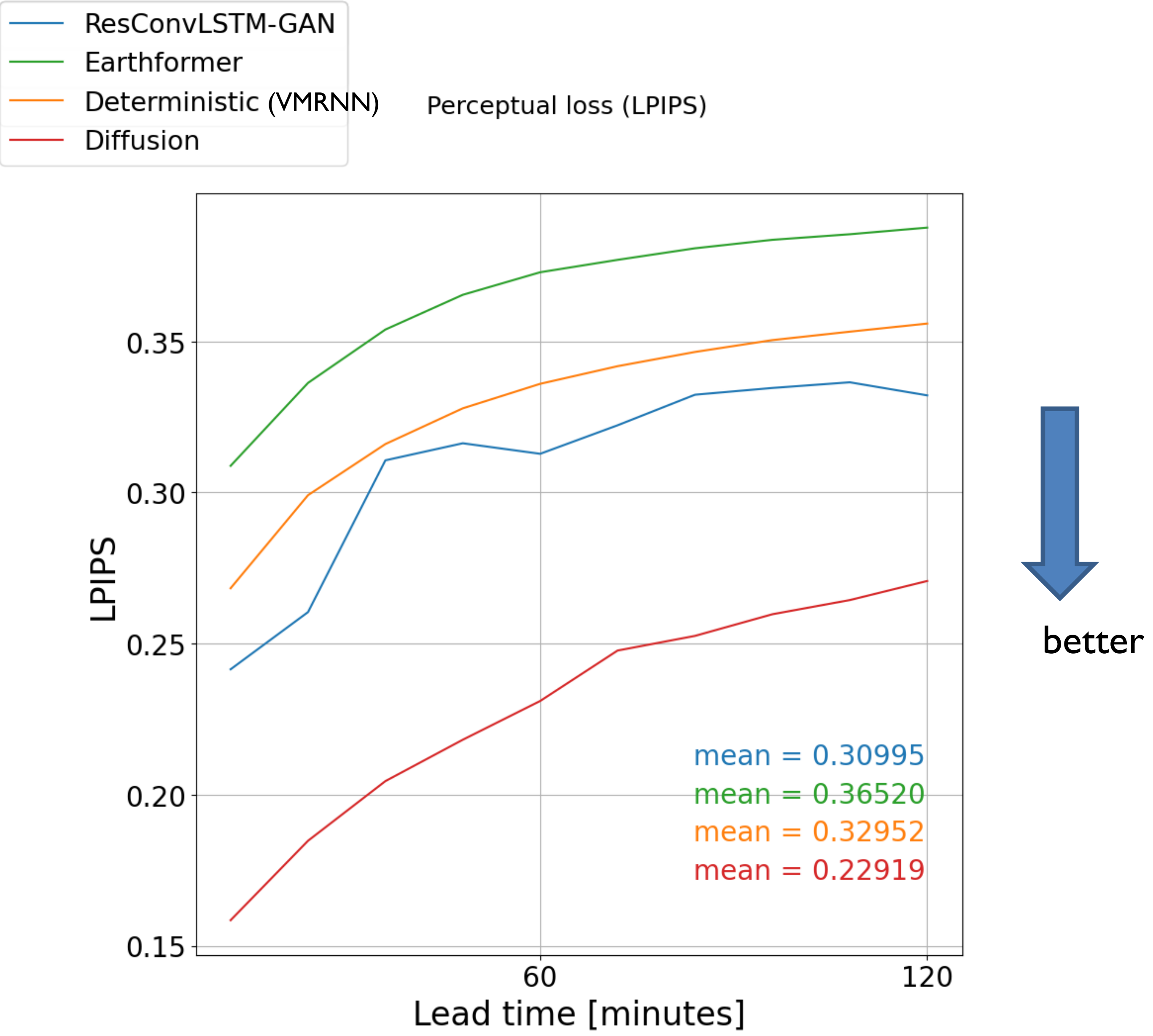


HSS

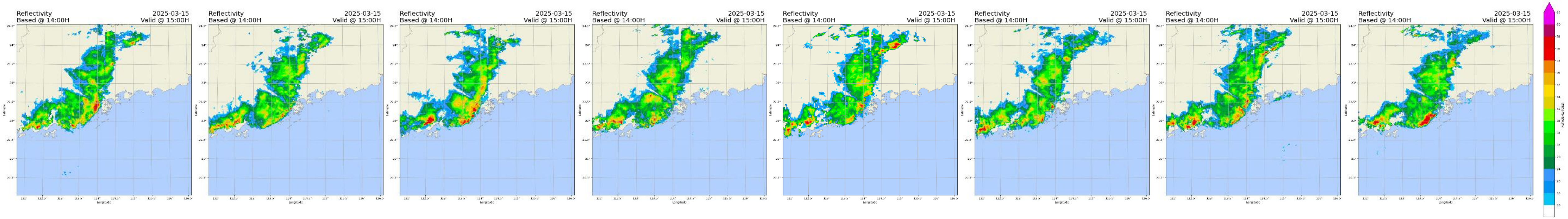
$$HSS = \frac{POC - POC_{\mathrm{random}}}{1 - POC_{\mathrm{random}}} = \frac{(H + Z) - (H_{\mathrm{random}} + Z_{\mathrm{random}})}{N - (H_{\mathrm{random}} + Z_{\mathrm{random}})}$$

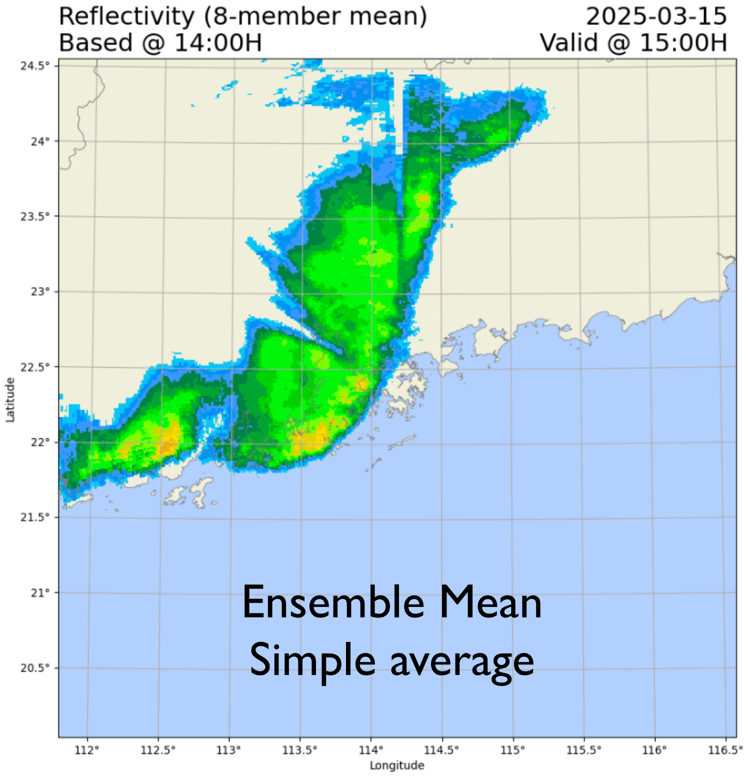


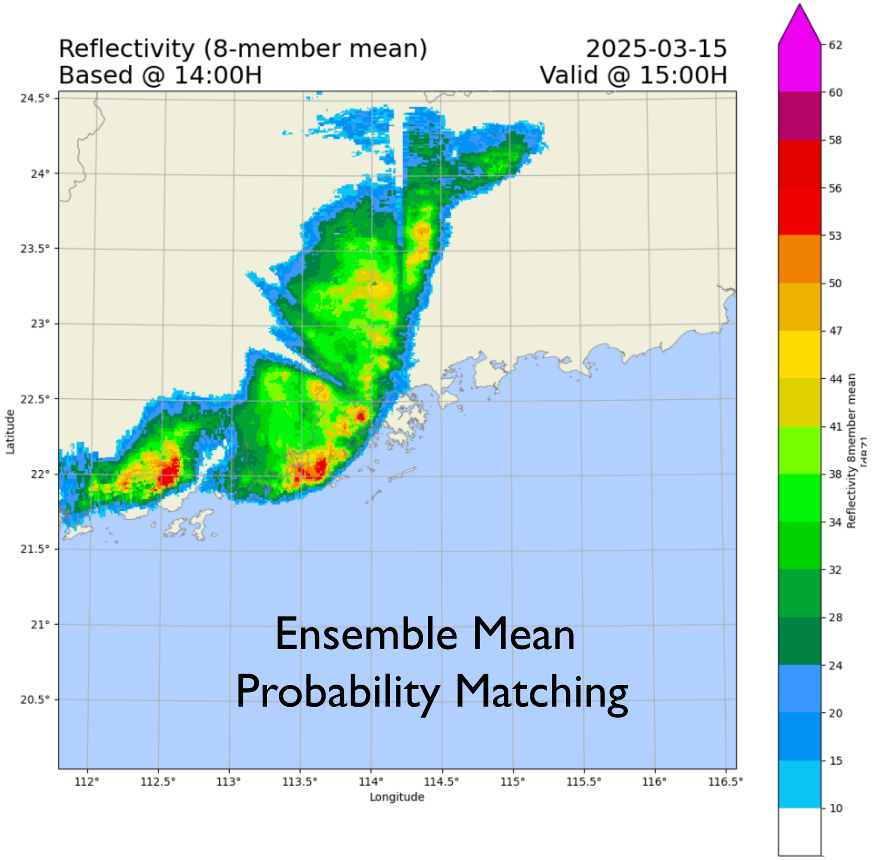
Verification Metric - Perceptual Similarity

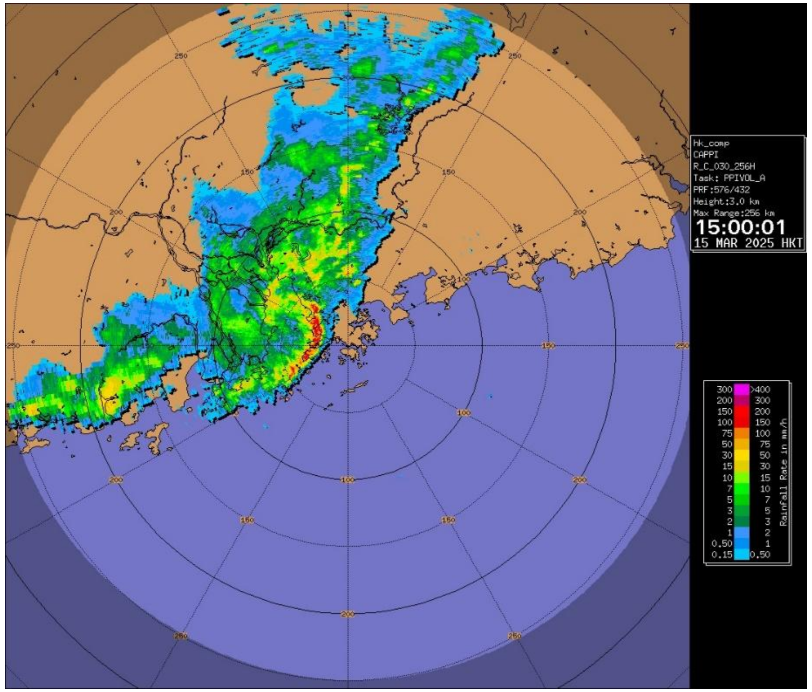


Diffusion Nowcast (8) Ensemble Members at T+60 min
Base time: 2025-03-15 14:00 HKT





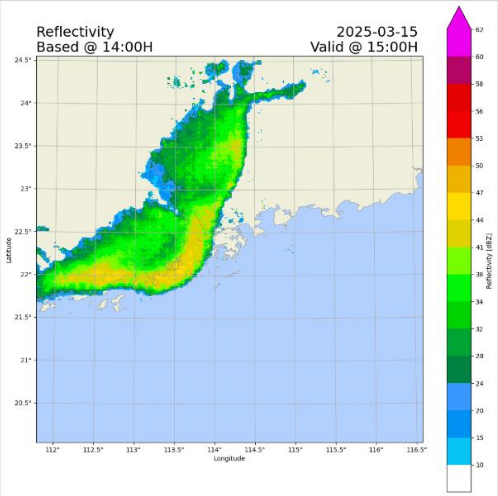




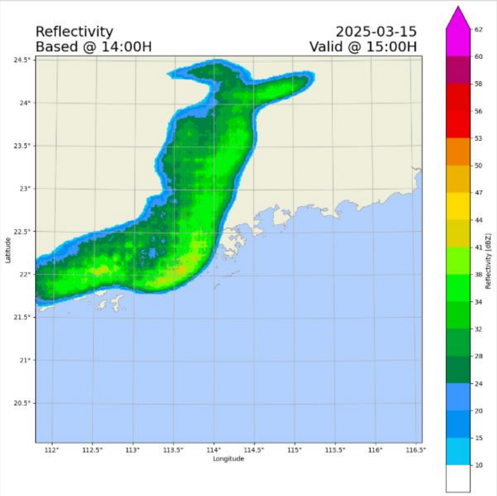
1-hour nowcasts from extrapolation and multi-model deep learning techniques

Base time: 2025-03-15 14:00 HKT

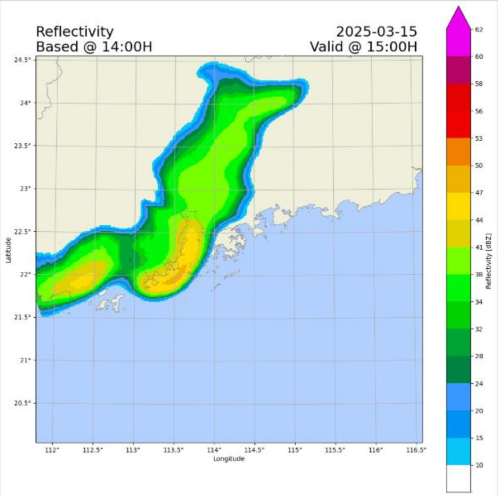
ResConvLSTM-GAN



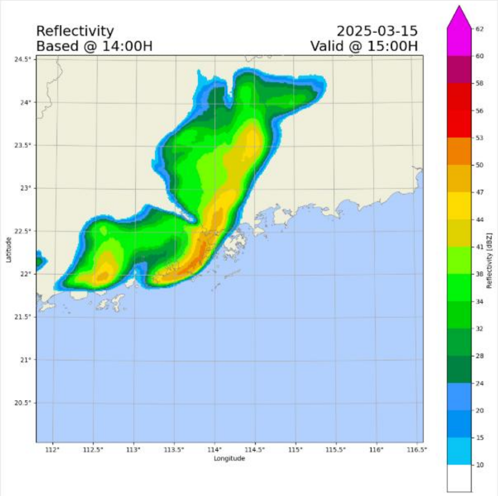
TrajGRU



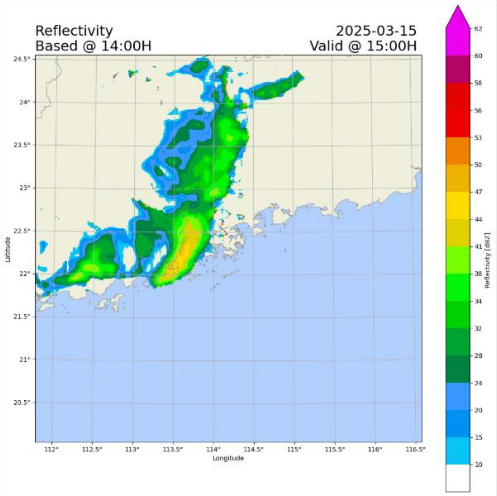
Earthformer



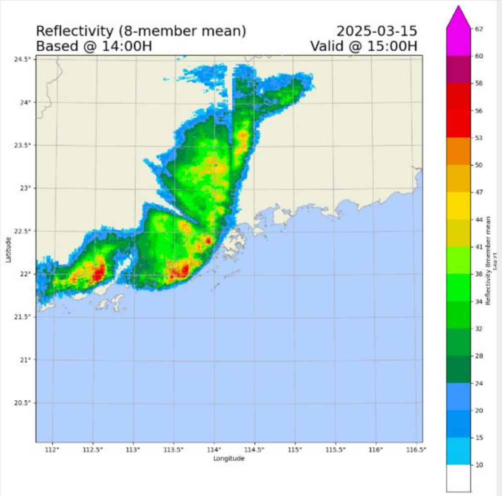
IAM4VP

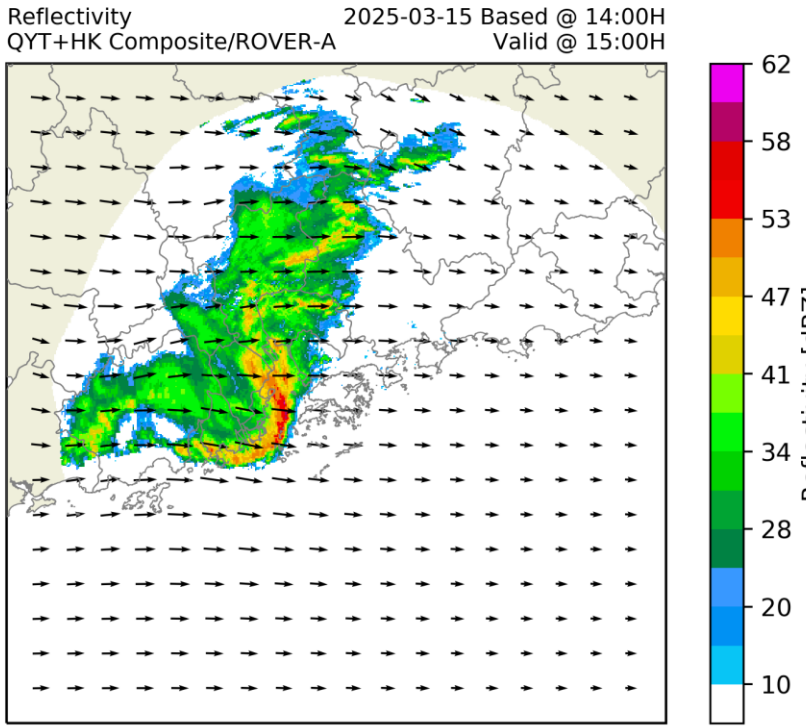


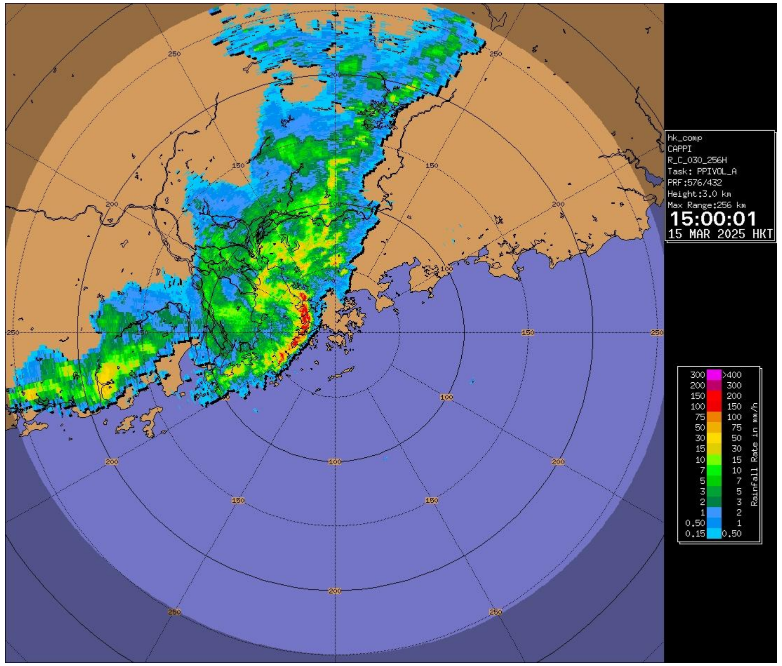
Fourier



Diffusion Ensemble Mean







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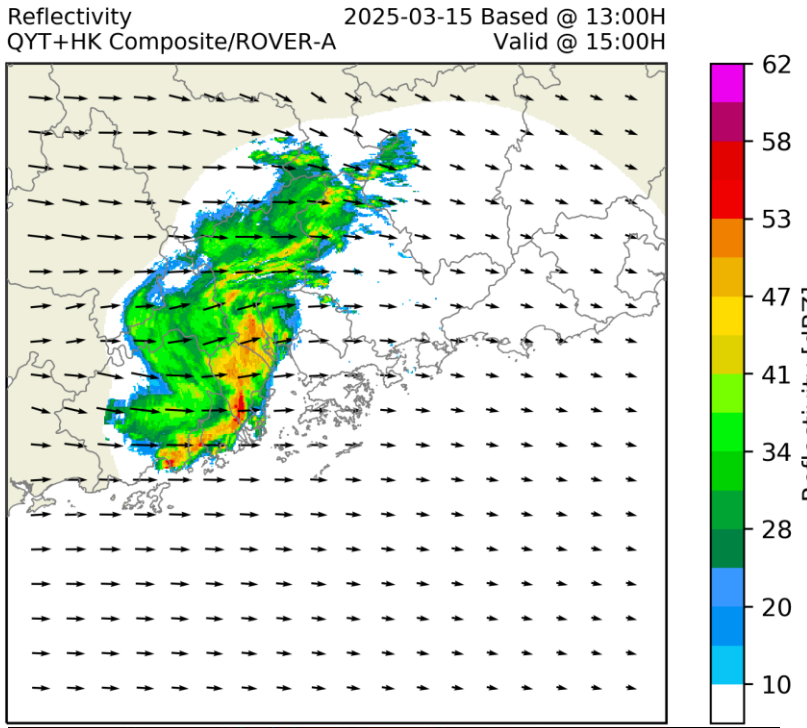
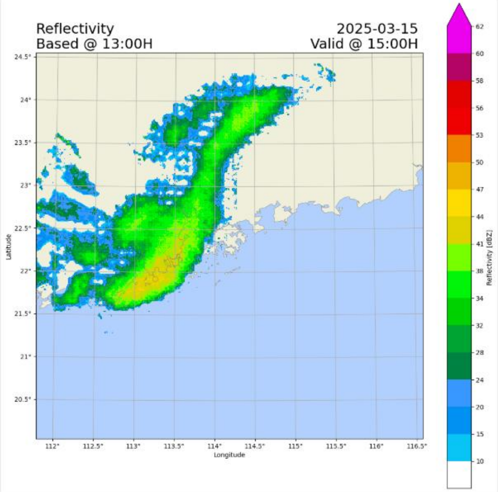
2-hour nowcasts from extrapolation and multi-model deep learning models

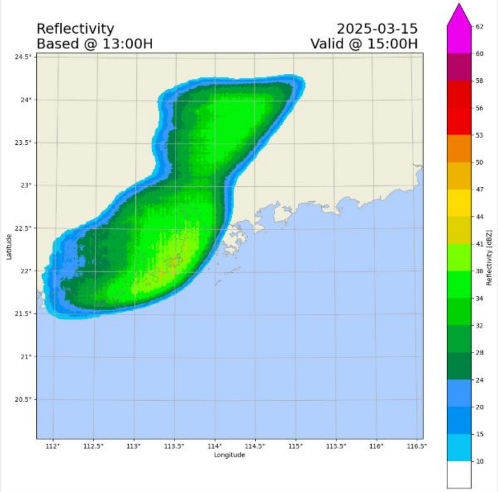
Base time: 2025-03-15 13:00 HKT



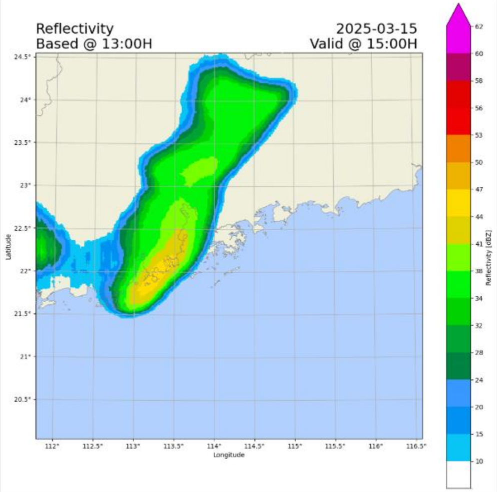
ResConvLSTM-GAN



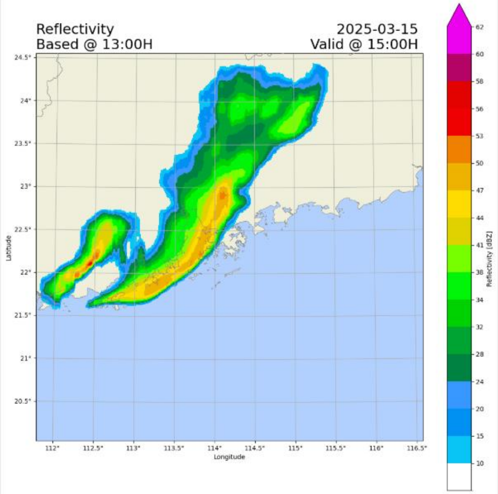
TrajGRU



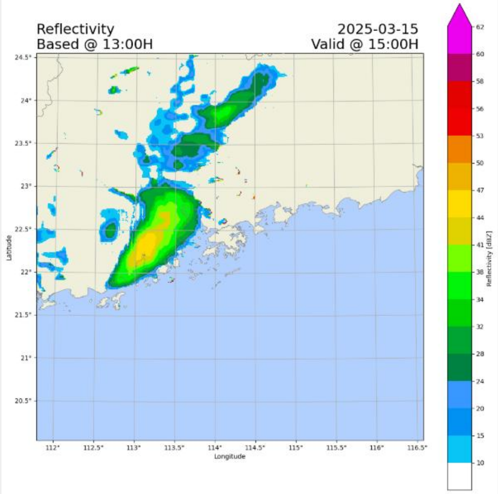
Earthformer



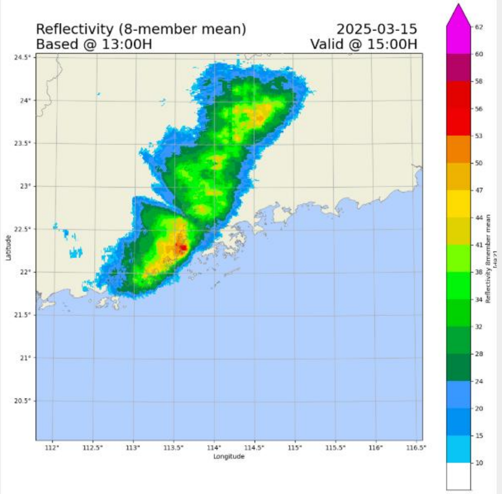
IAM4VP

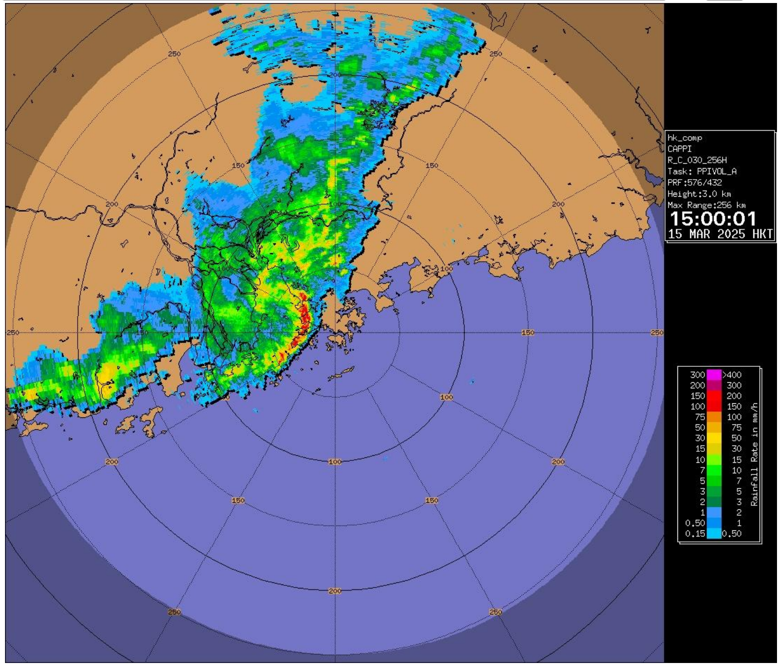


Fourier



Diffusion Ensemble Mean





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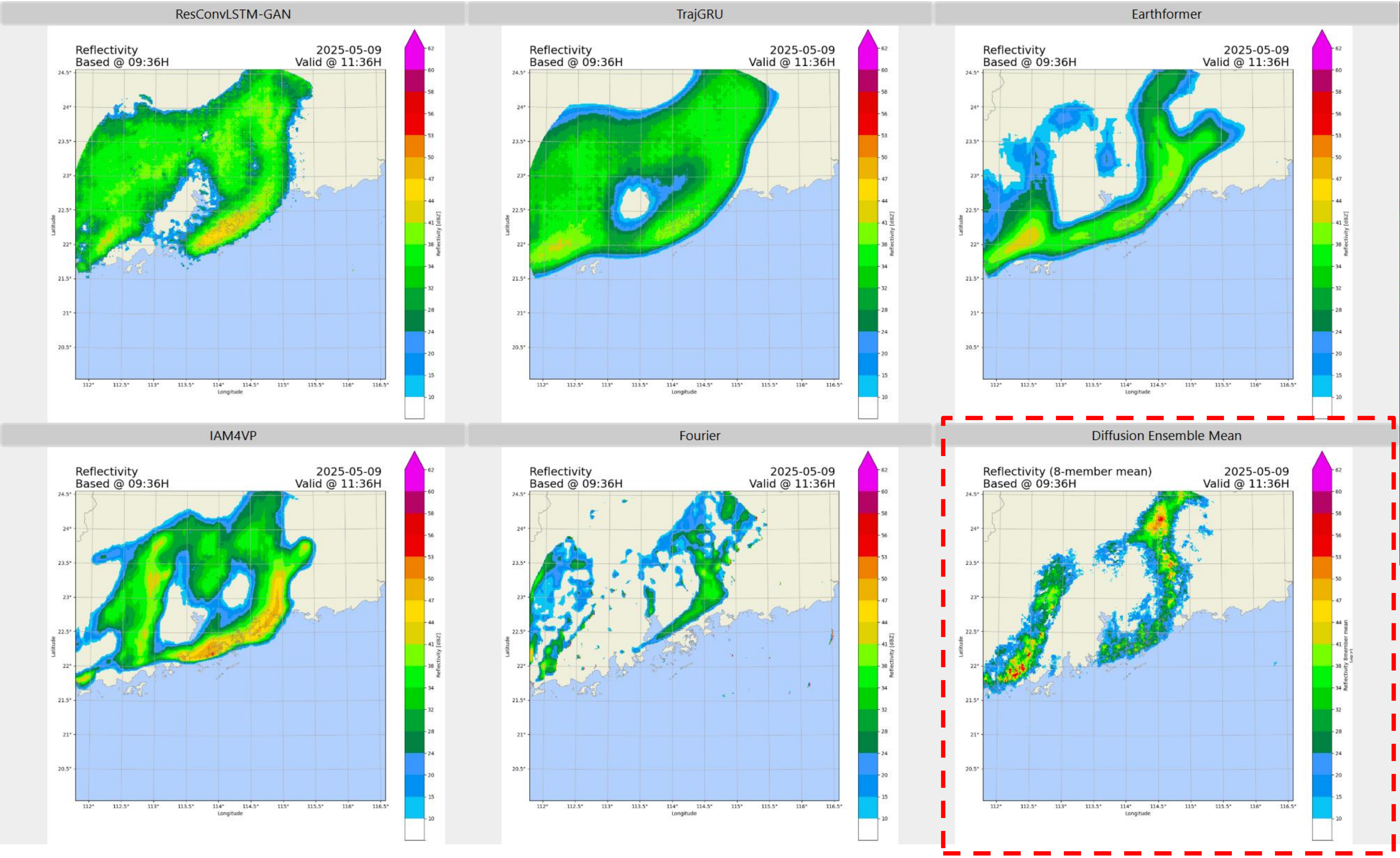
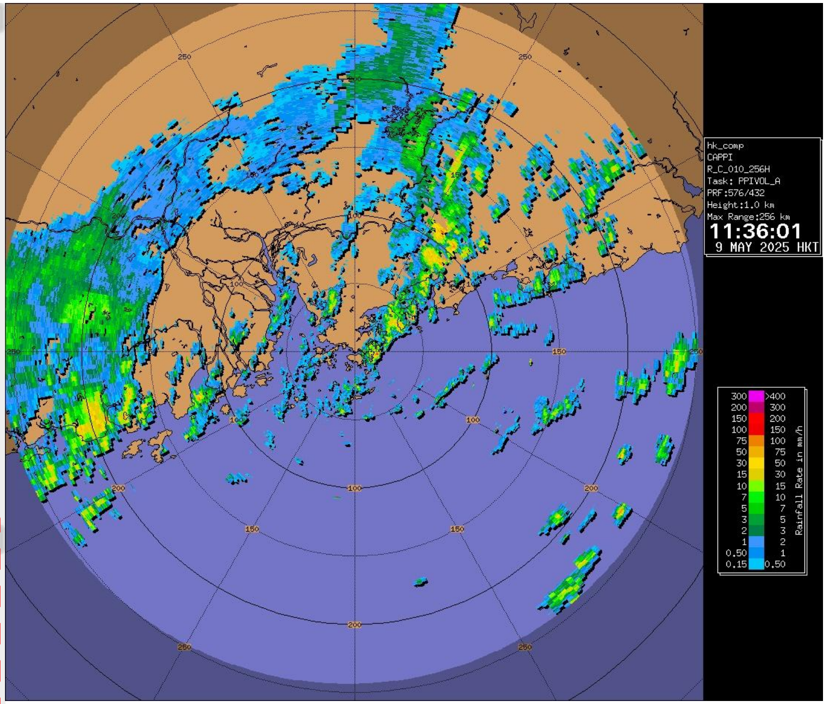
T+120 min nowcasts from deep learning models

2025-05-09 11:36 HKT





AI nowcast models showing two major convective areas over HK and PRD in T+2h nowcast, with Earthformer and Diffusion Ensemble picking up more stronger development to the west of PRD.

In comparison, ResConvLSTM and IAM4VP indicate a stronger development over HK and its vicinity to the east.

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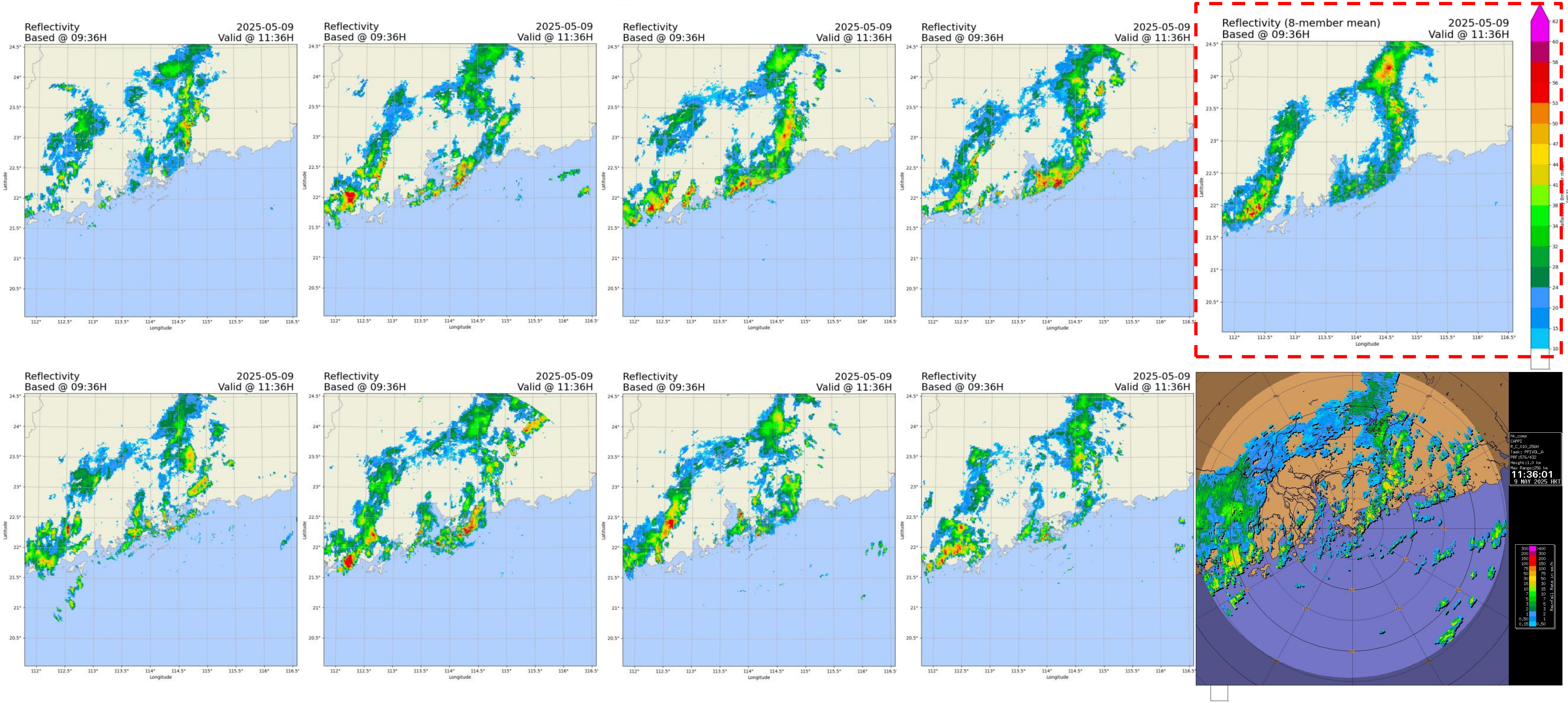
Diffusion ensemble members having different intensity / distribution of convection over HK; while “more agreeable” on the stronger convective development over the western part of the coastal areas ➔ ensemble consensus producing more realistic indication on the difference in their intensities

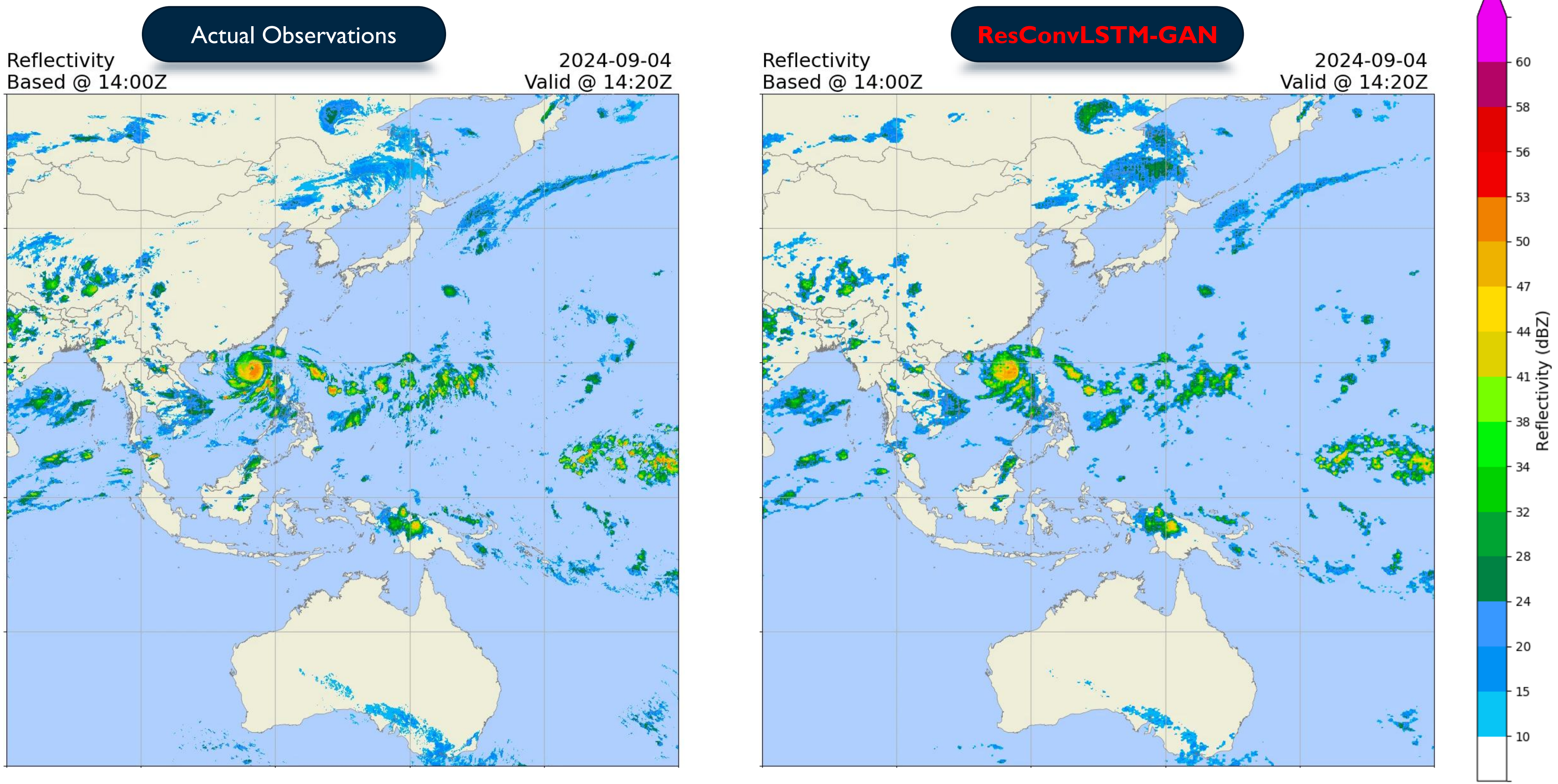
T+120 min nowcasts from DDPM members

2025-05-09 11:36 HKT



Deep Learning Models in Regional Nowcasting Supports

Use of AI/ML in nowcasting – Precipitation and Significant Convection



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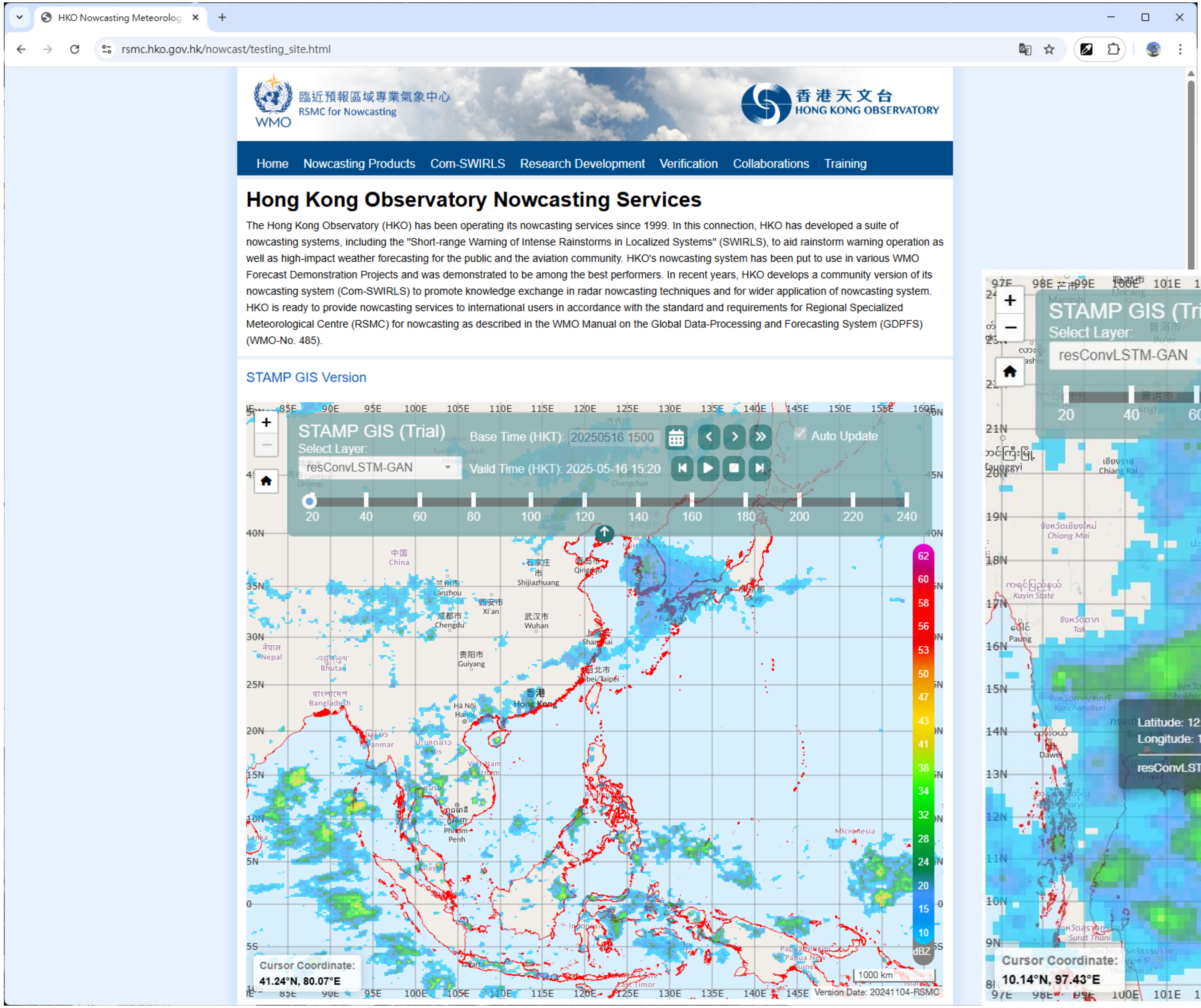
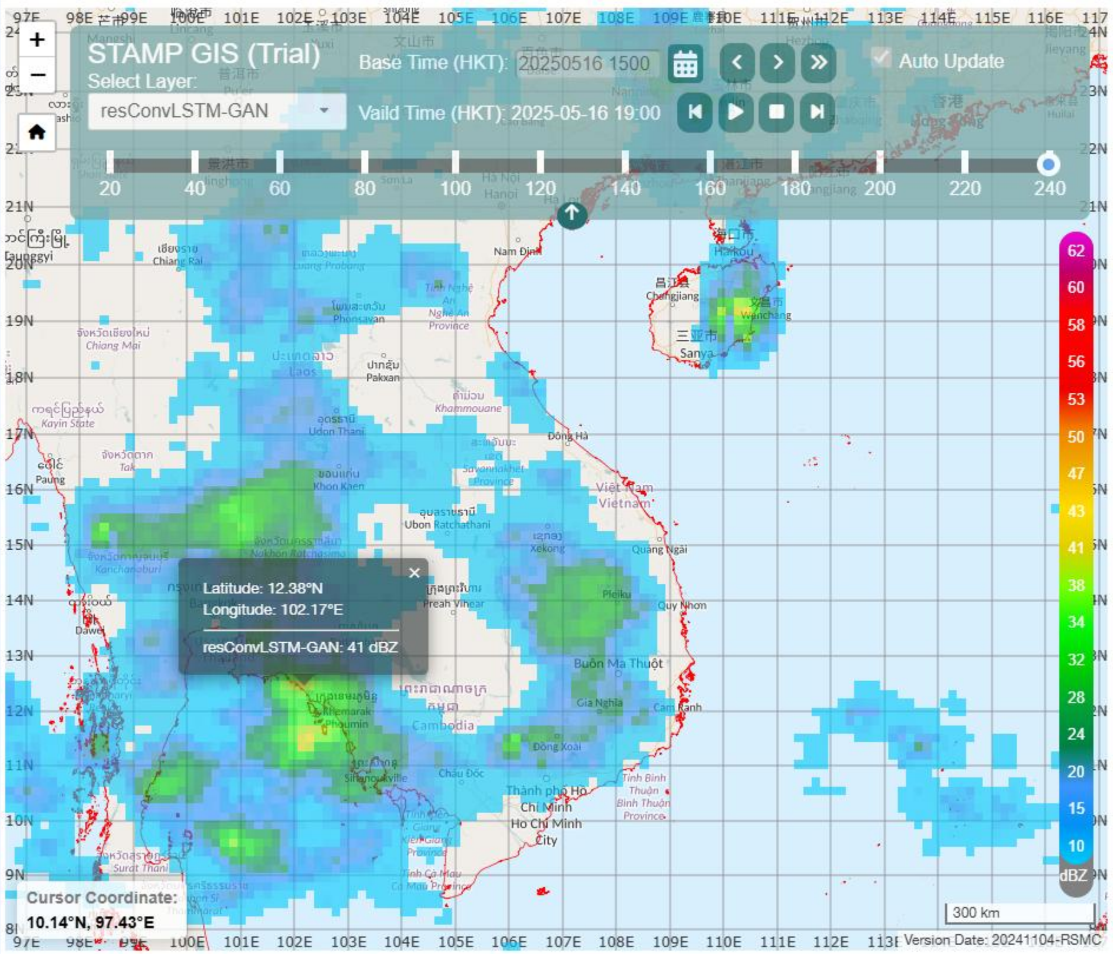
臨近預報區域專業氣象中心 RSMC for Nowcasting WMO



Web-GIS tool showing AI/ML nowcast product and interactive visualization

(upcoming version of RSMC for Nowcasting website)



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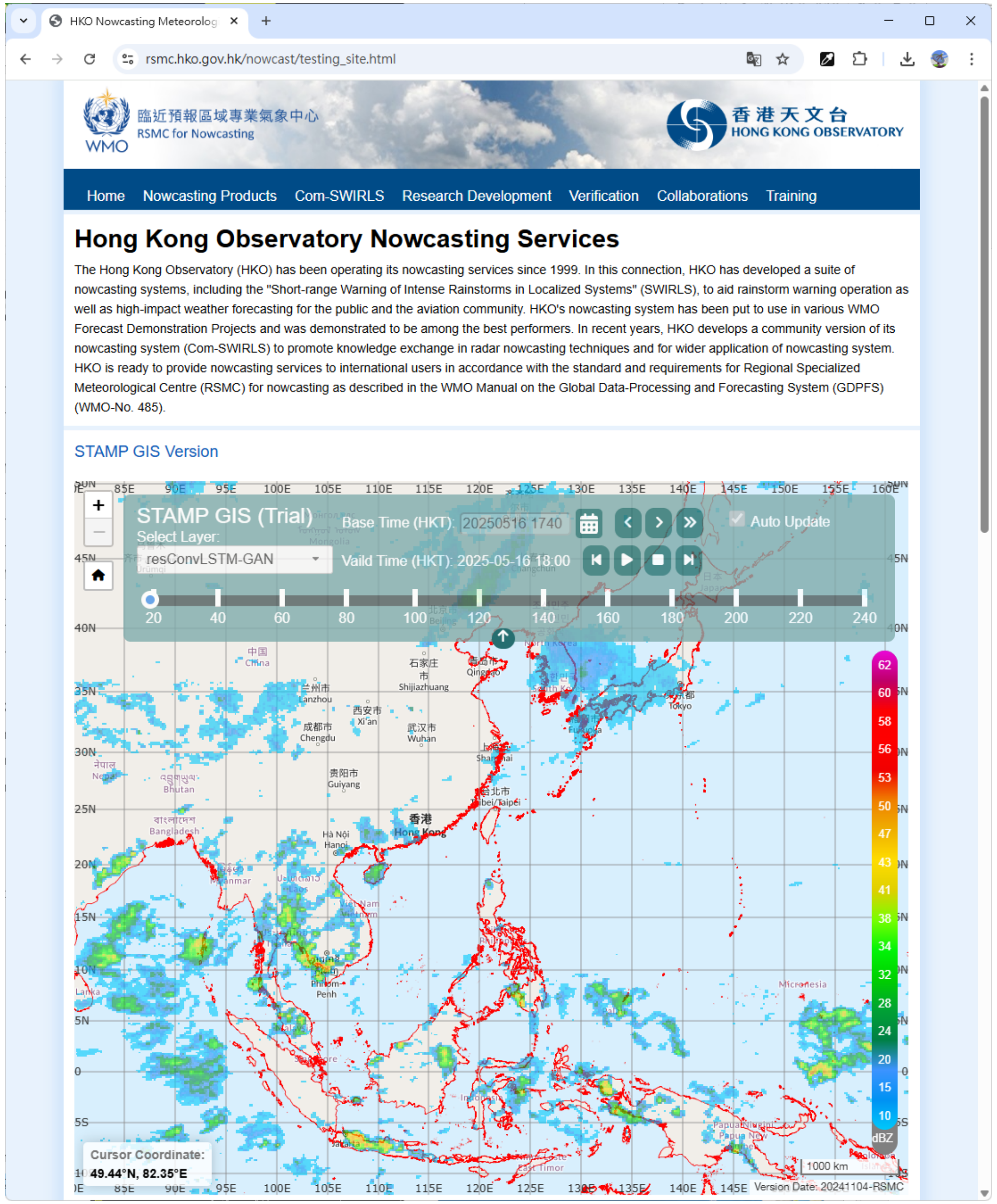
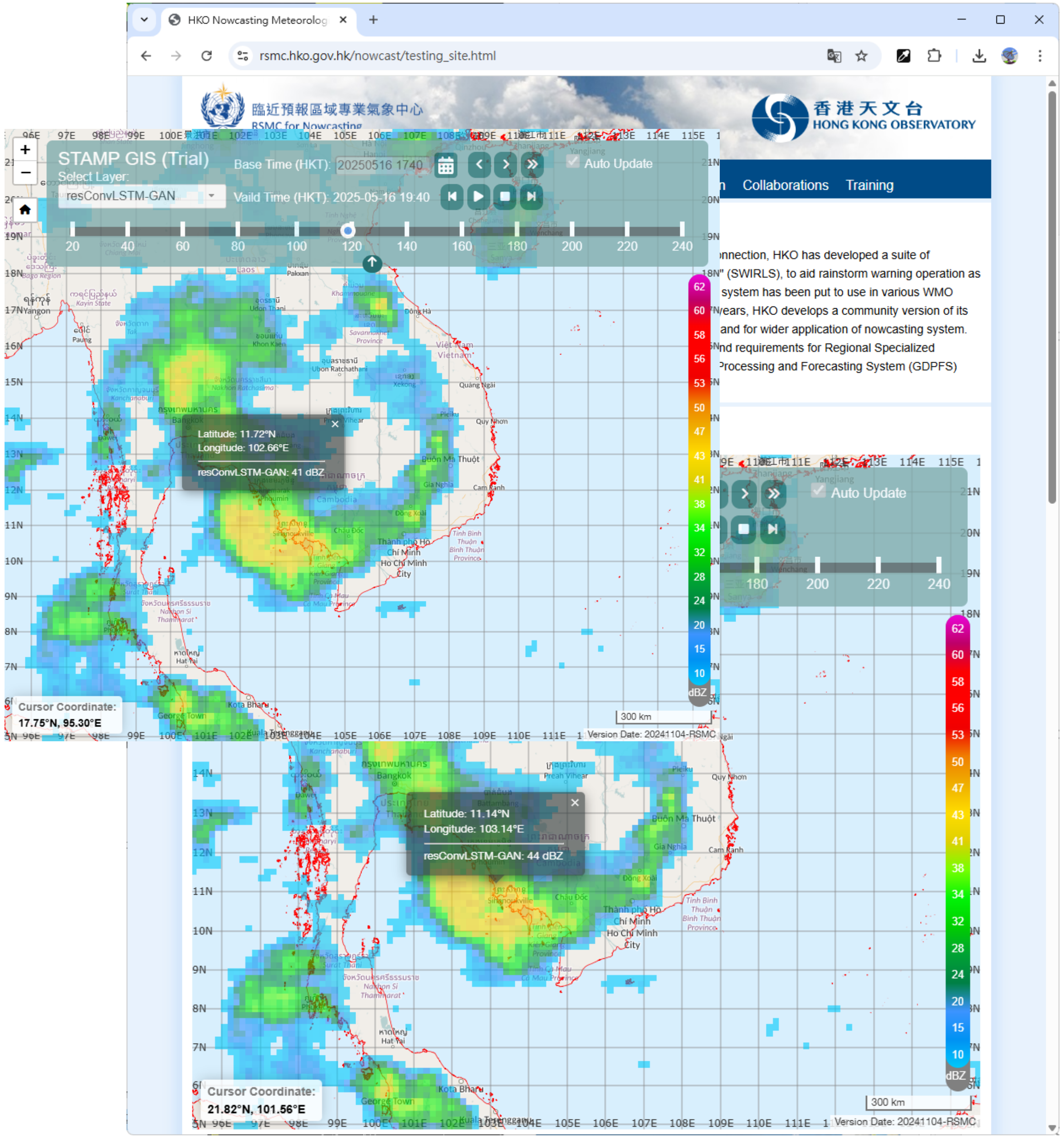
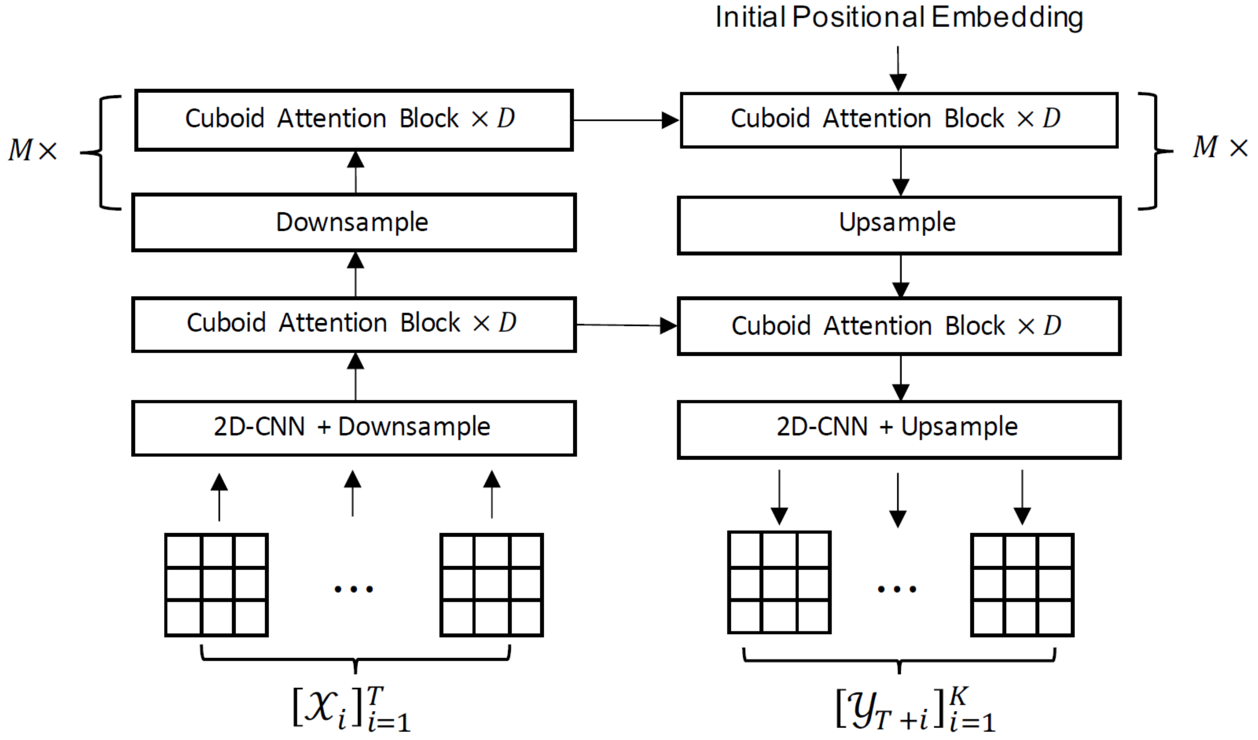
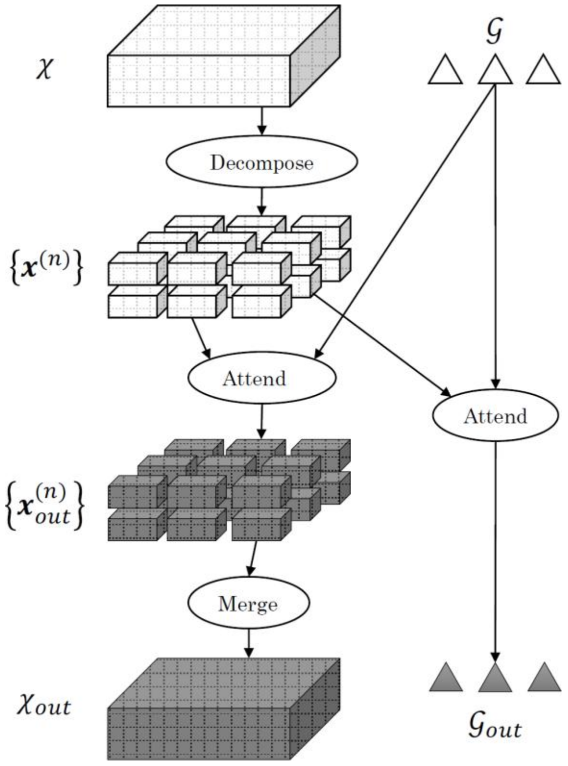
臨近預報區域專業氣象中心 RSMC for Nowcasting



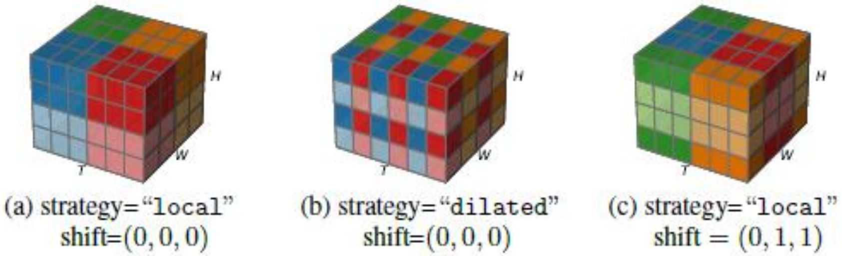


Earthformer





Cuboid attention layer with global vectors



Cuboid decomposition strategies in attention layer

- **Space-time Transformer** model based on Cuboid Attention
- Spatiotemporal data are divided into non-overlapping cuboids, and **self-attention** is applied locally within each cuboid
- **Global vectors** are used to connect the cuboids for capturing the overall pattern

https://arxiv.org/abs/2207.05833

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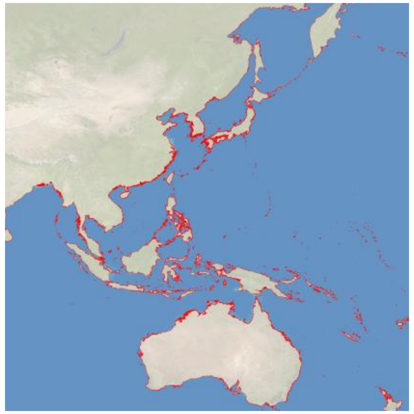
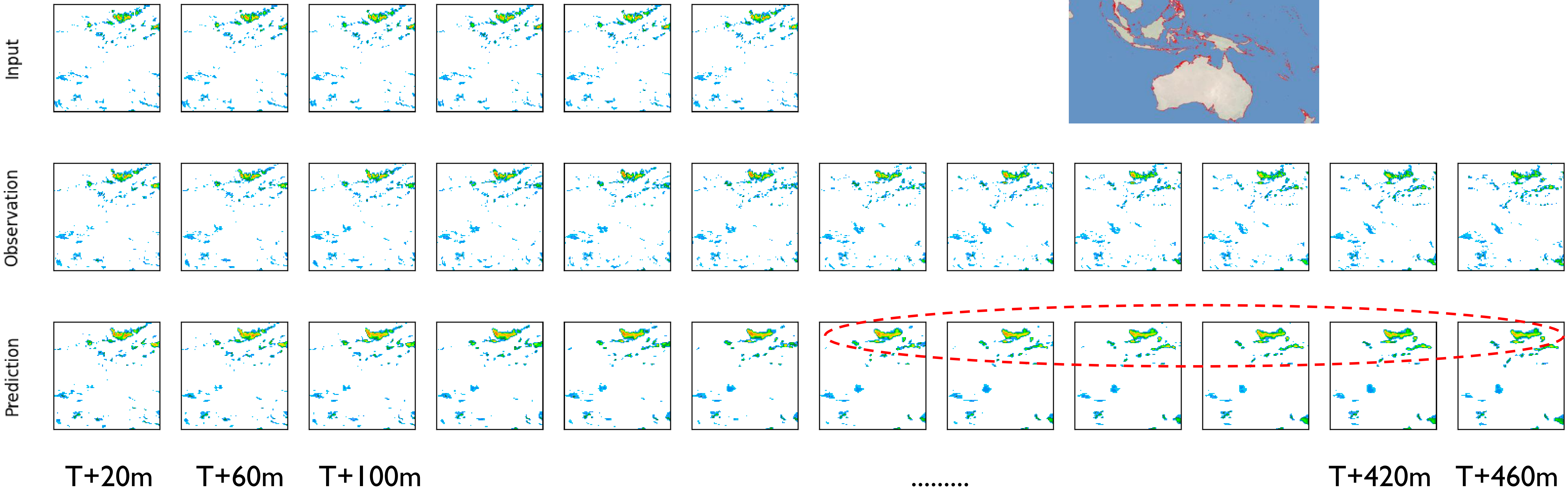
Extending satellite retrieved reflectivity nowcast using Earthformer





Preserving intensity in T+ 4 to T+8 hours

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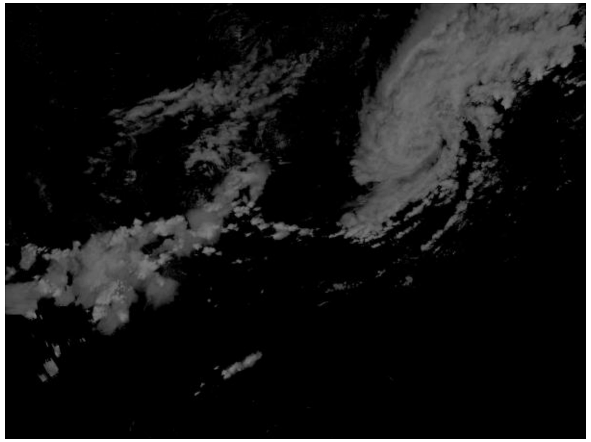
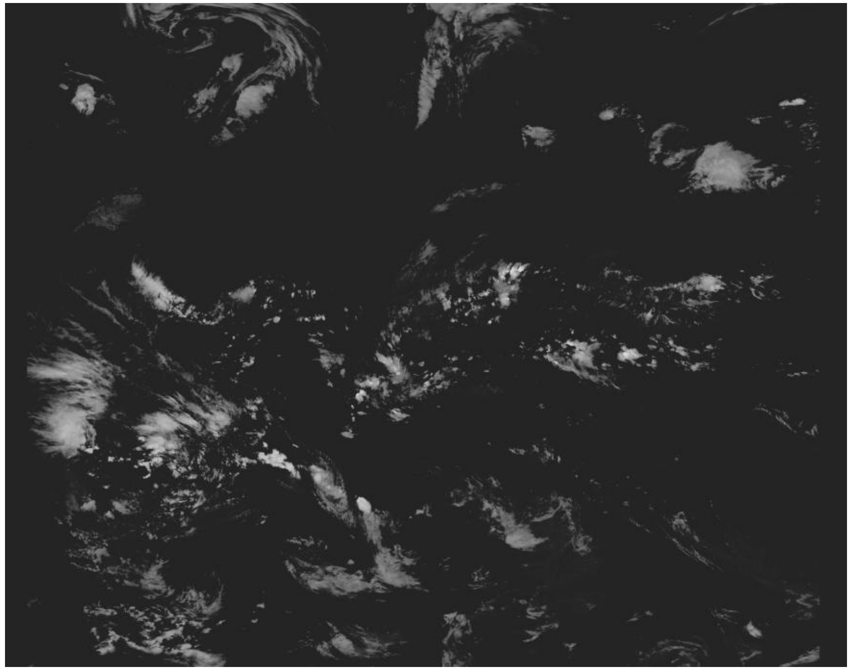
Earthformer for CMA radar composite with H9/GK2A satellite simulated reflectivity in AINPP intercomparison project

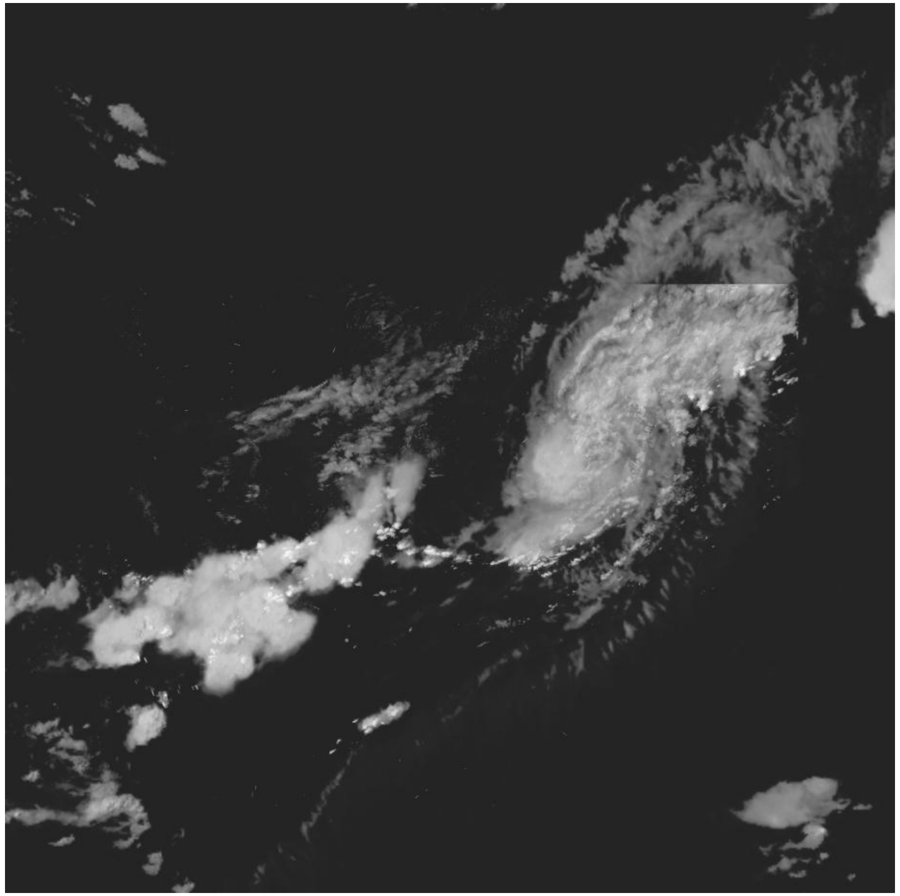
CMA radar composite for AINPP intercomparison experiments

18-30N 104-120E



Simulated reflectivity using H9/GK2A imagers composite





Mosaic reflectivity imagery
16.00-36.48N, 101.76-122.24E @ 0.01 deg
(2048 x 2048 pixels)

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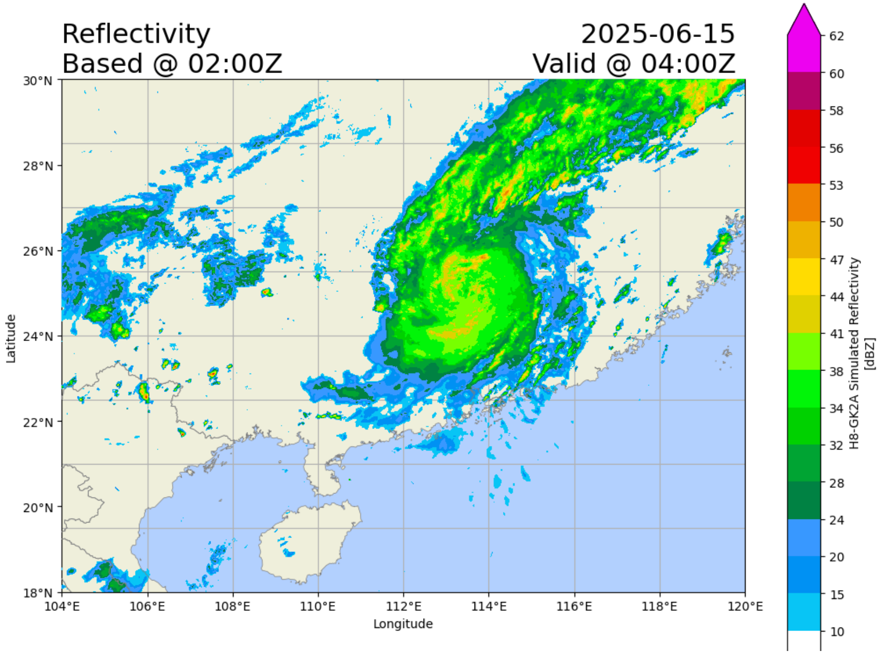
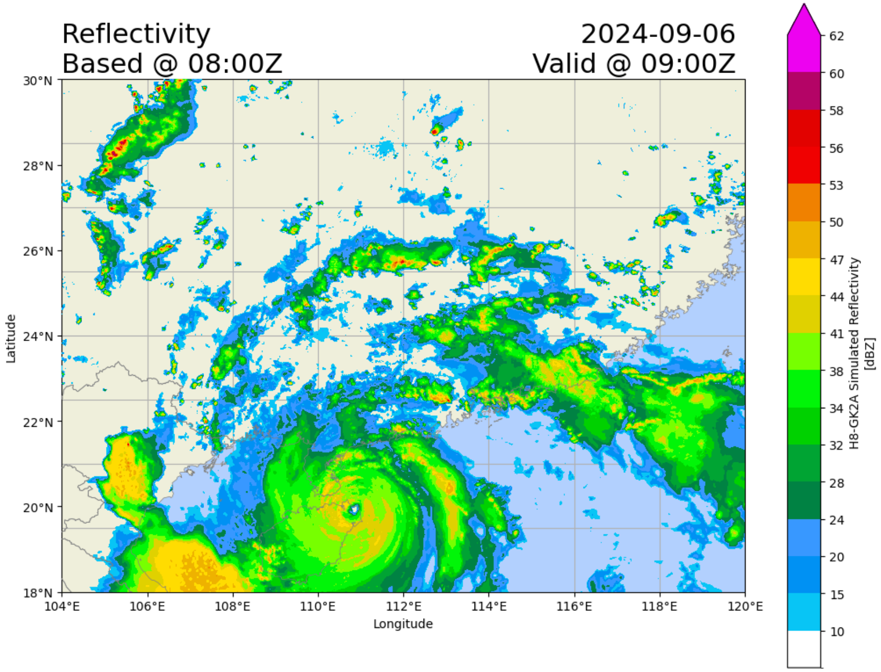
WMO 臨近預報區域專業氣象中心 RSMC for Nowcasting

Satellite-Radar Composite Reflectivity

Date range	Training / Validation set: Mar 2023 to Oct 2024
Domain coverage	2048 x 2048 grid from 16 to 36.48N; 101.76 to 122.24E (0.01x 0.01 deg)
Input data	6 maps with 20 minutes interval (2 hours of observations)
Output data	24 maps with 20 minutes interval (8 hours regional reflectivity nowcast)





Earthformer T+1 to T+8h Nowcasts
2025-06-15 09:20Z

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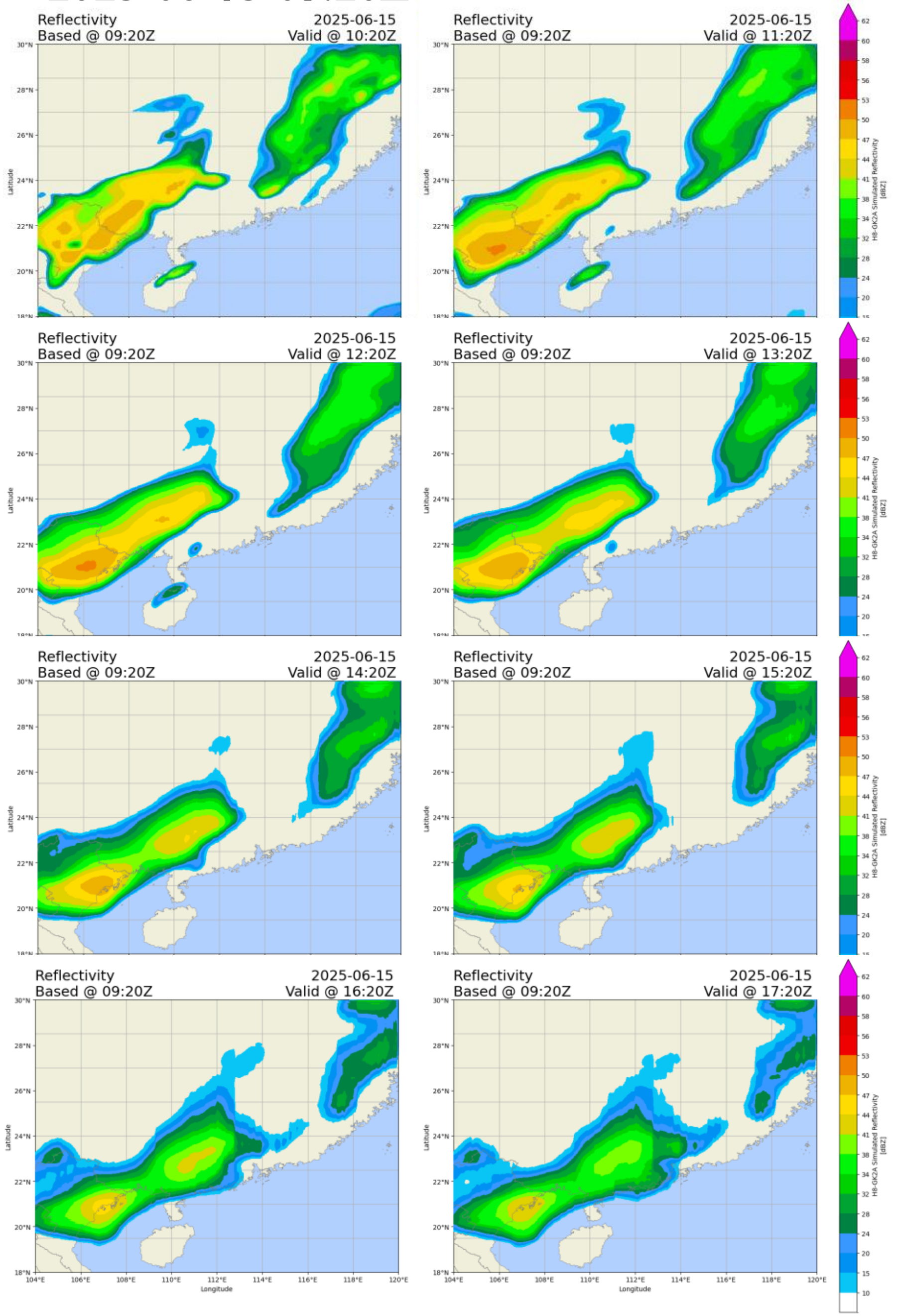
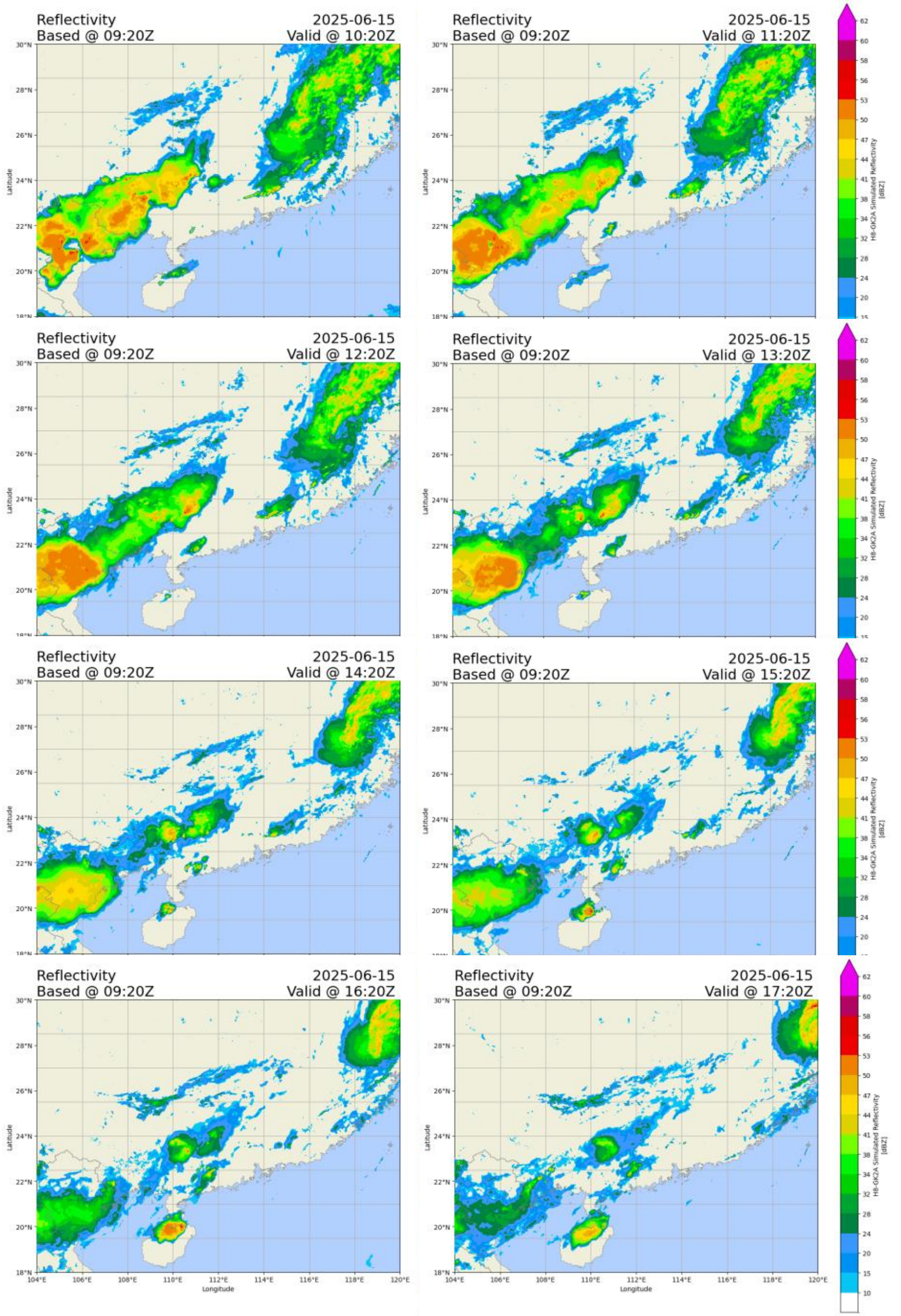
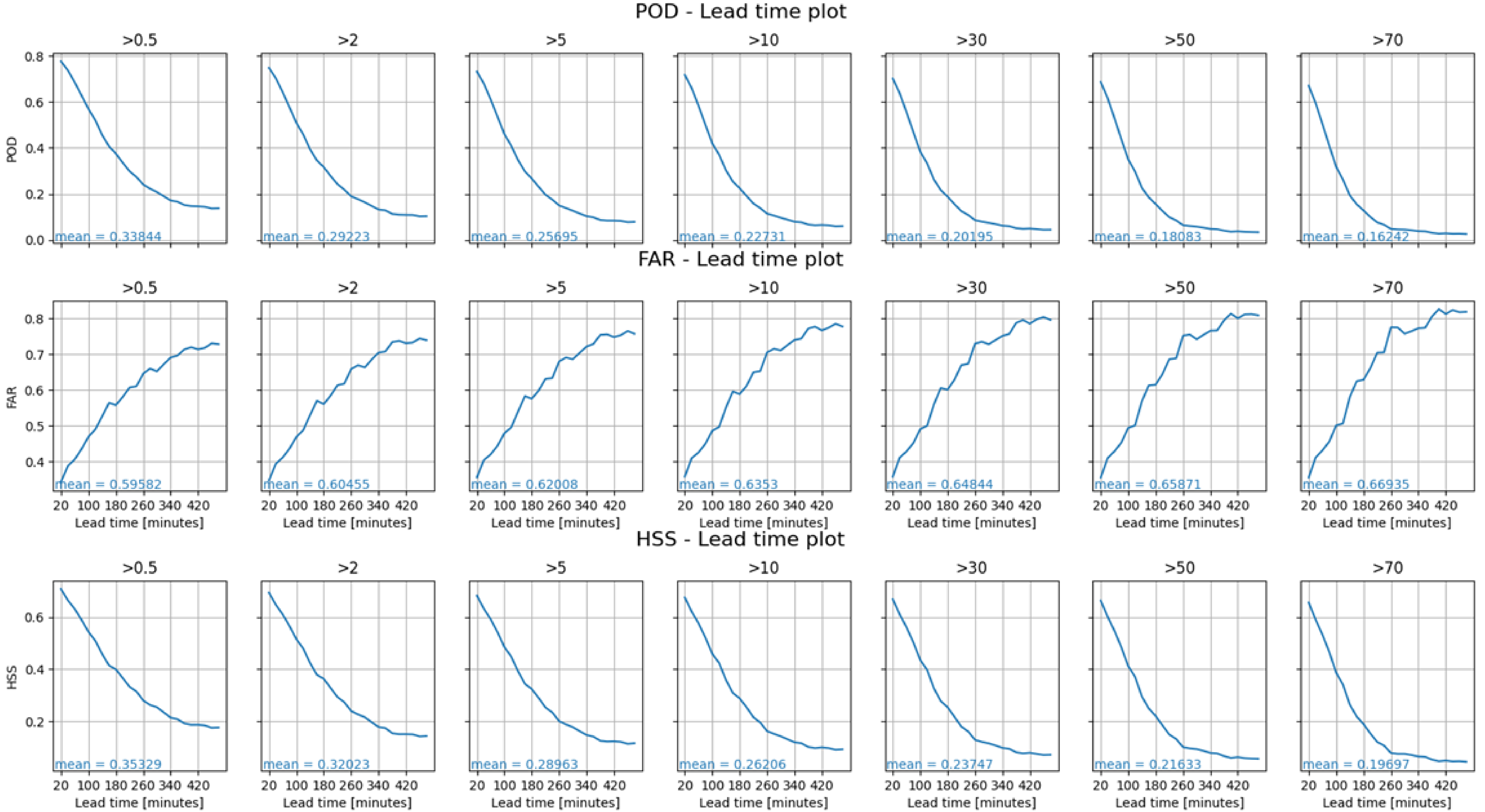
WMO 臨近預報區域專業氣象中心 RSMC for Nowcasting



Actual reflectivity composite



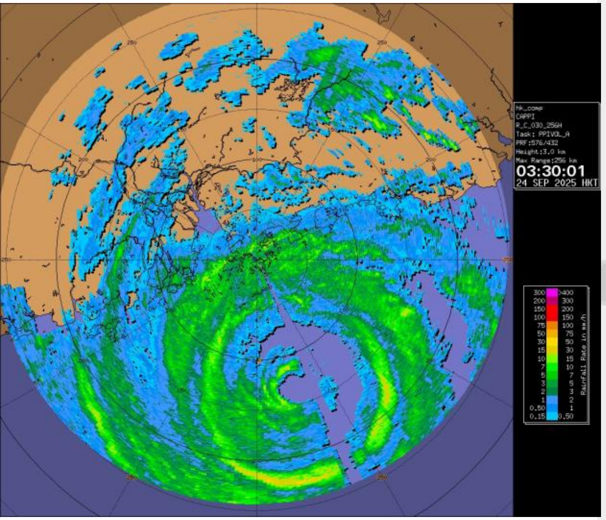
Verification – POD, FAR and HSS

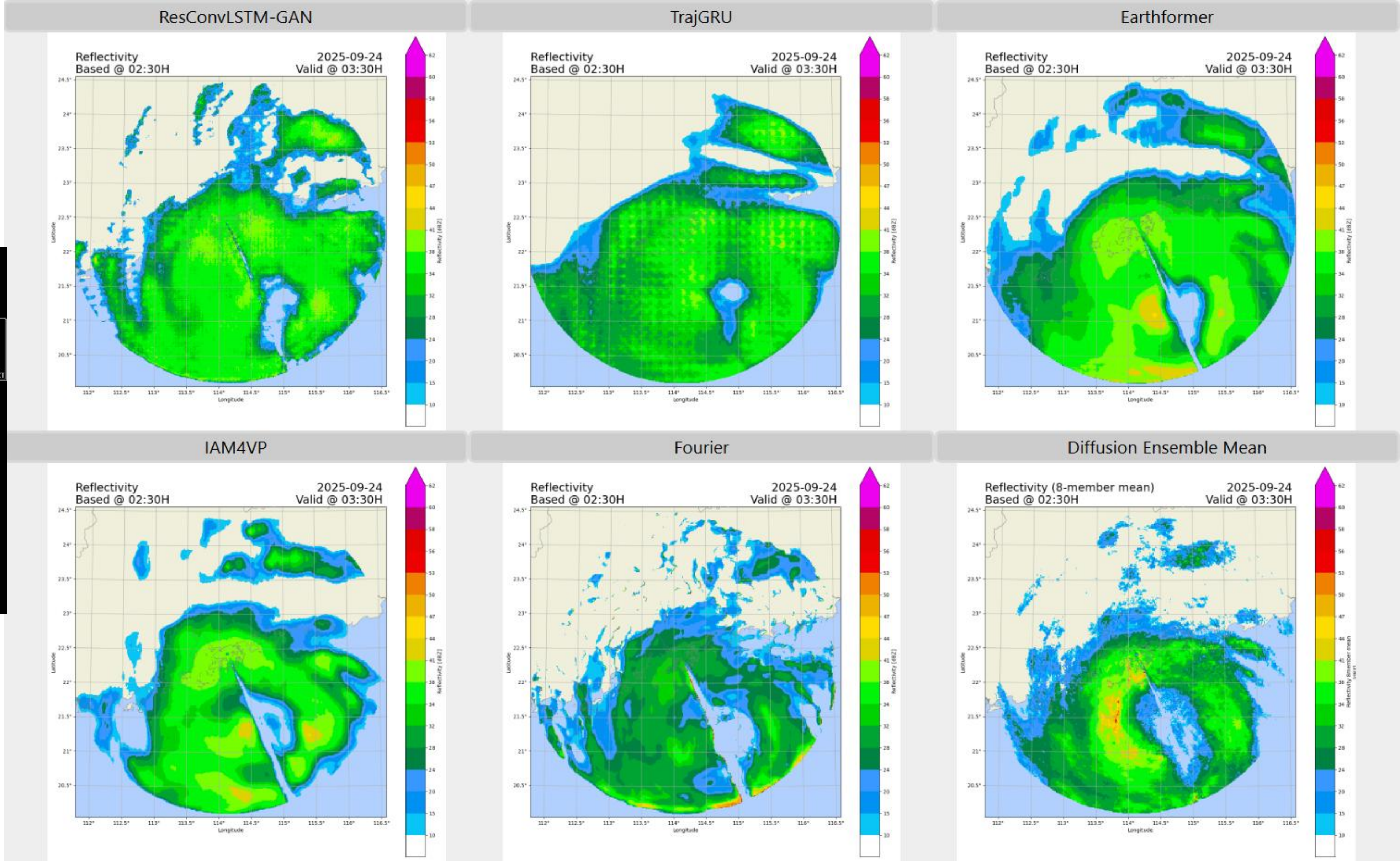


Ensemble Nowcast and AI-based Guidance in Extreme Precipitation Prediction

Super Typhoon Ragasa (2025-09-24)

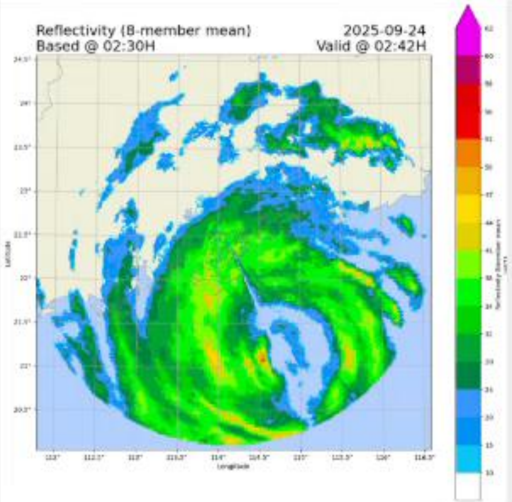
T+1h nowcast from
6 deep learning
algorithms



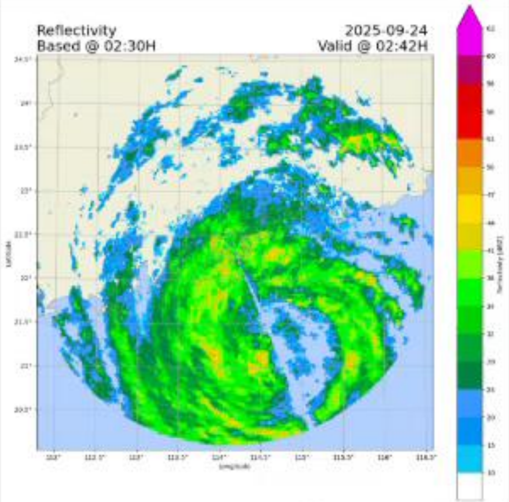


Ensemble Mean and 8 Diffusion Ensemble Members

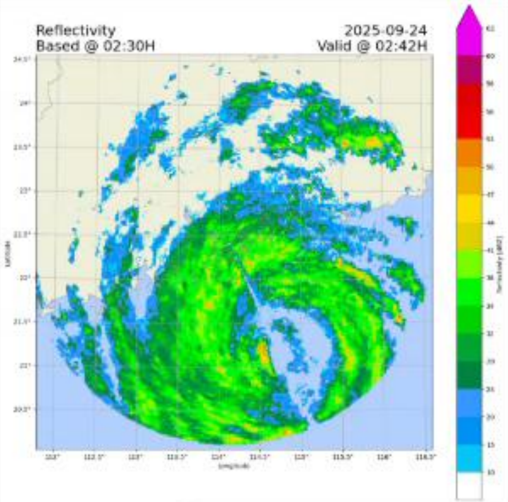
Ensemble Mean



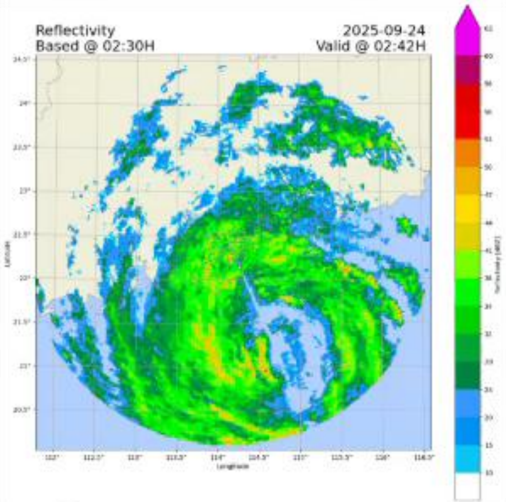
Member 1



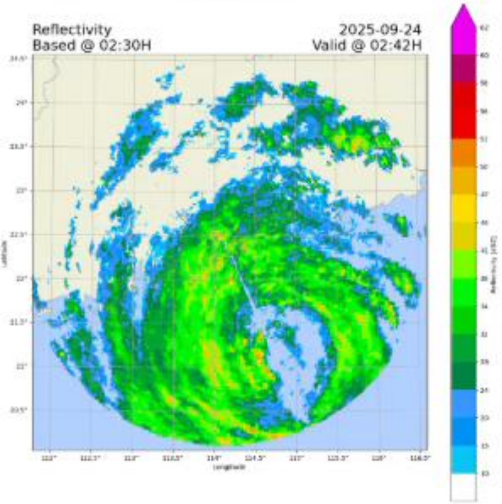
Member 2



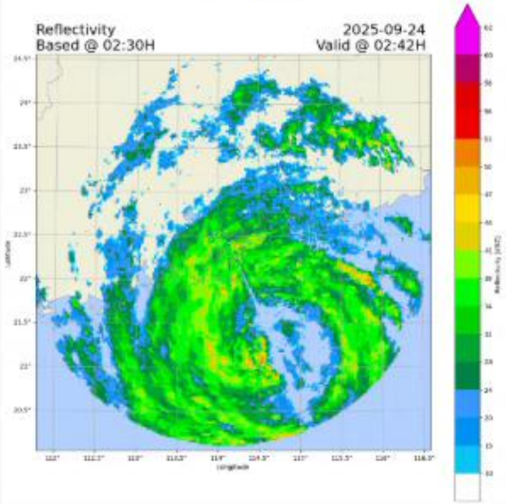
Member 3



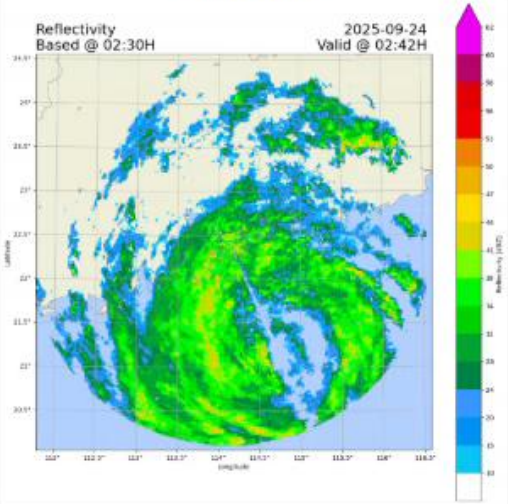
Member 4



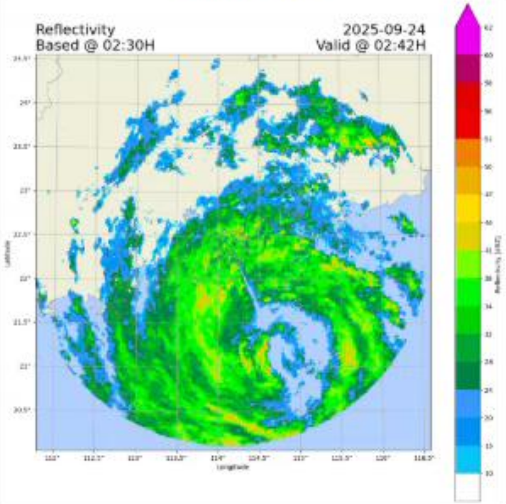
Member 5



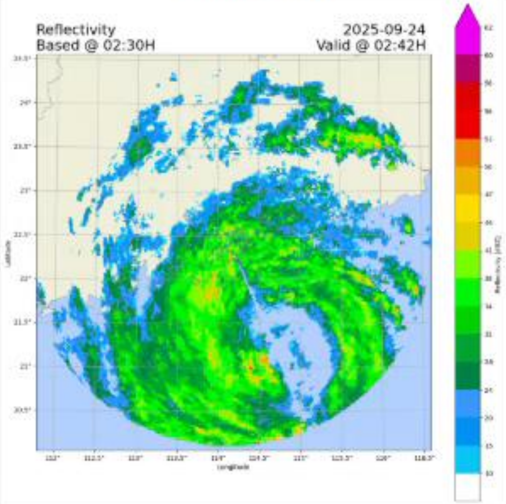
Member 6



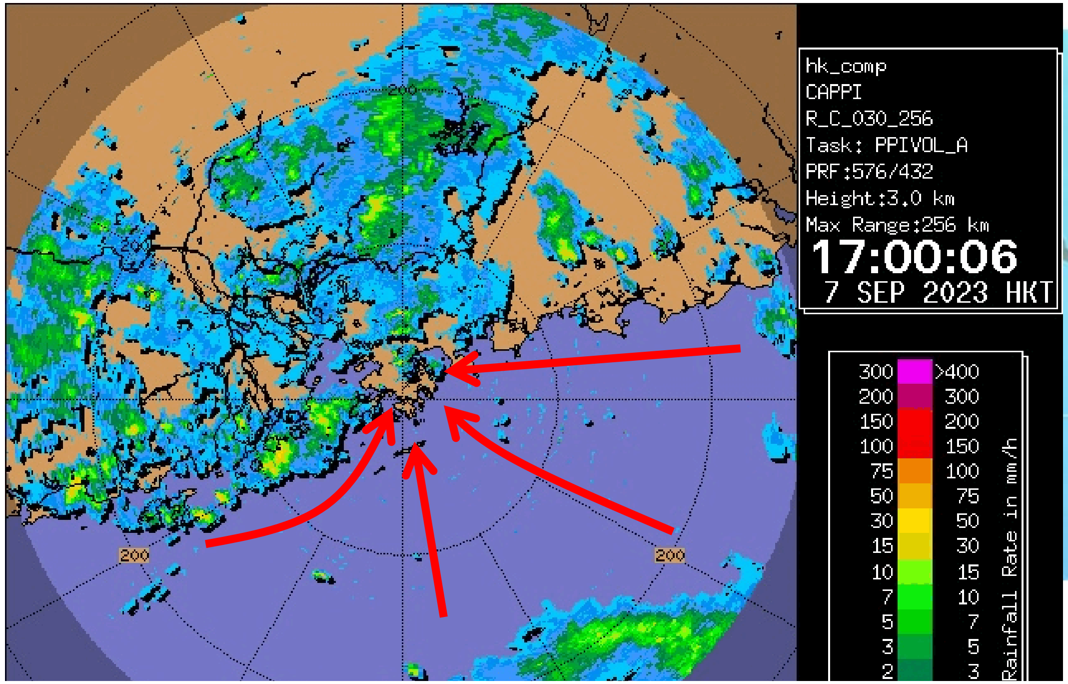
Member 7

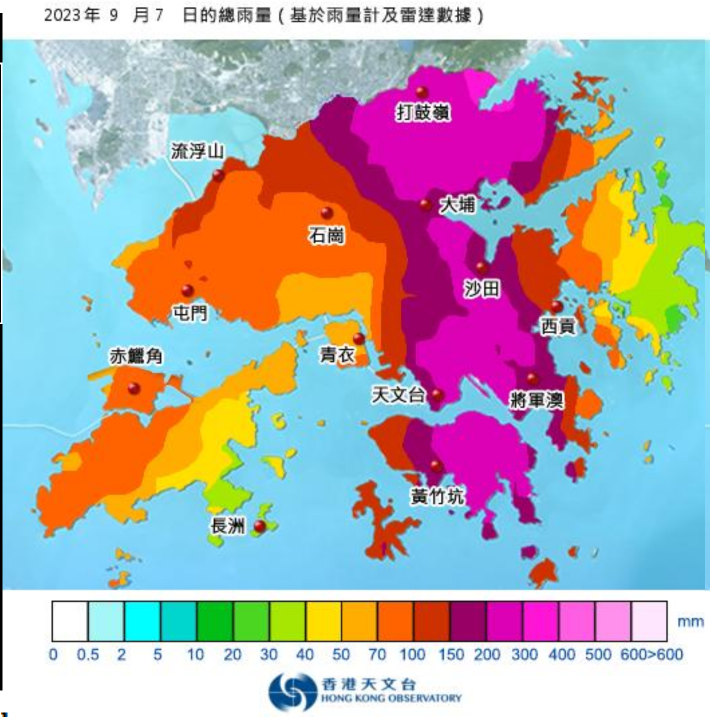


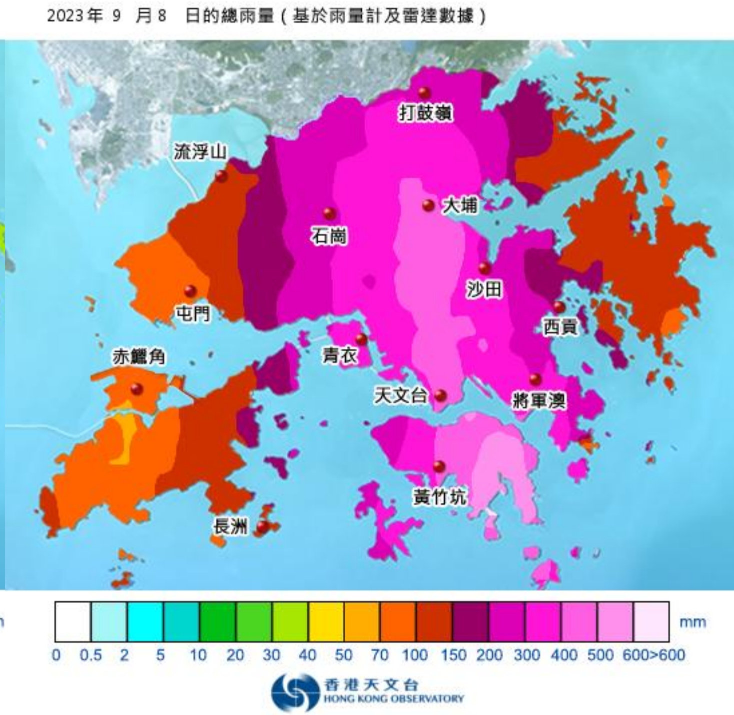
Member 8



Exceptionally severe rainstorm on 7-8 September 2023







100 Highest 1-Hour Total Rainfall (mm) at the Hong Kong Observatory for All Months

No	Rank	Total Rainfall	Date	Ending Hour (HKT)
1	1	158.1	2023.09.07	24
2	2	145.5	2008.06.07	09
3	3	115.1	2006.07.16	03
4	4	109.9	1992.05.08	07
5	5	108.2	1966.06.12	07
6	6	105.9	2023.09.08	08
7	7	104.8	1989.05.02	13
8	8	100.7	1926.07.19	04
9	9	100.0	1968.06.13	03
10	10	98.7	1972.06.18	12

Highest Daily Total Rainfall (mm) at Hong Kong Observatory for All Months

Record Since: 1884.03.01, exclude 1940-1946

No	Rank	Total	Date of record
1	1	534.1	1926.07.19
2	2	520.6	1889.05.30
3	3	425	2023.09.08
4	4	411.3	1998.06.09
5	5	382.6	1966.06.12
6	6	346.7	1983.06.17
7	7	342.3	1886.07.15
8	8	334.2	1982.08.16
9	9	329.7	2021.10.08
10	10	325.5	1965.09.27

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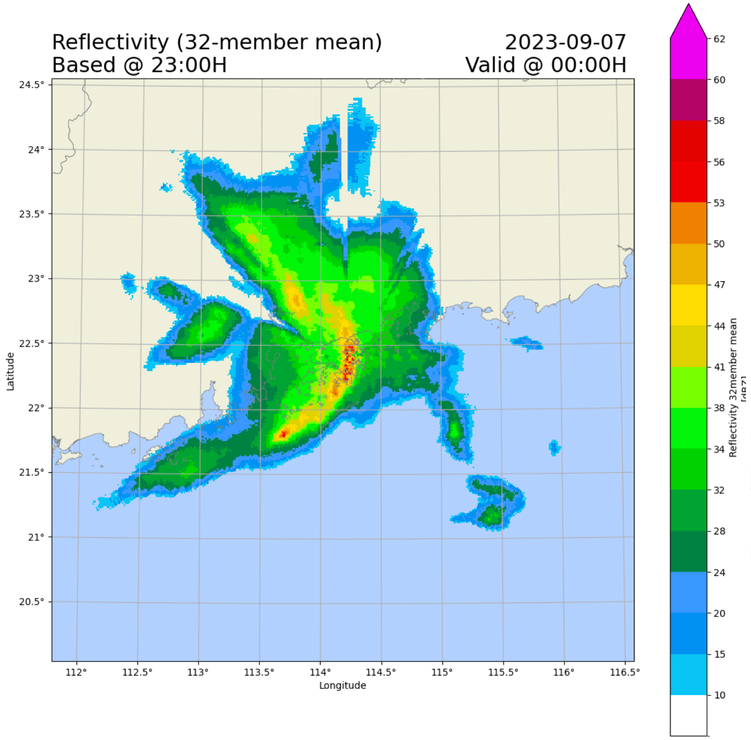
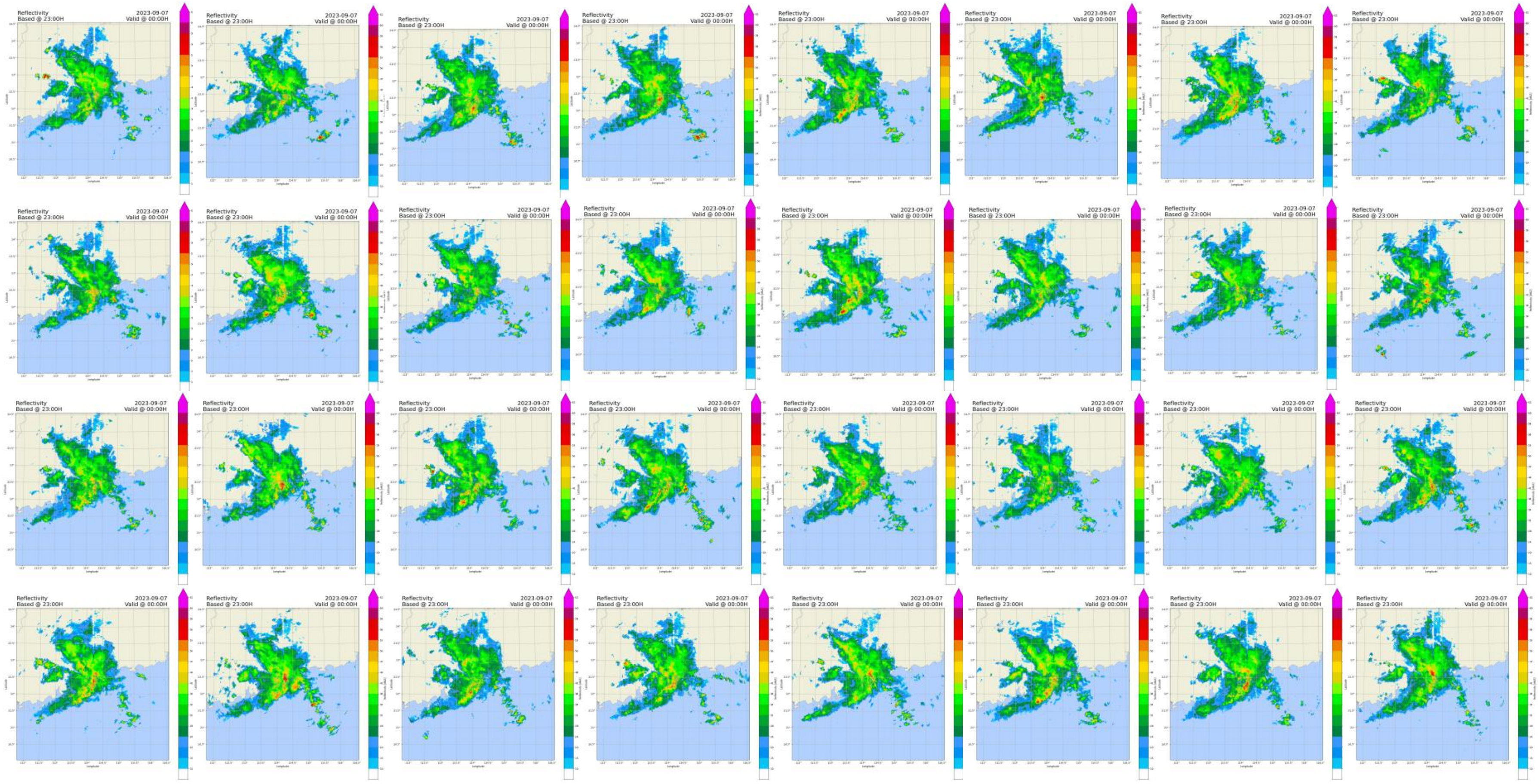
32-member DDPM ensemble

➔ Dynamic z-R relationship based on CAPPI reflectivity and raingauges in HK ($z = a R^b$) to generate hourly rainfall





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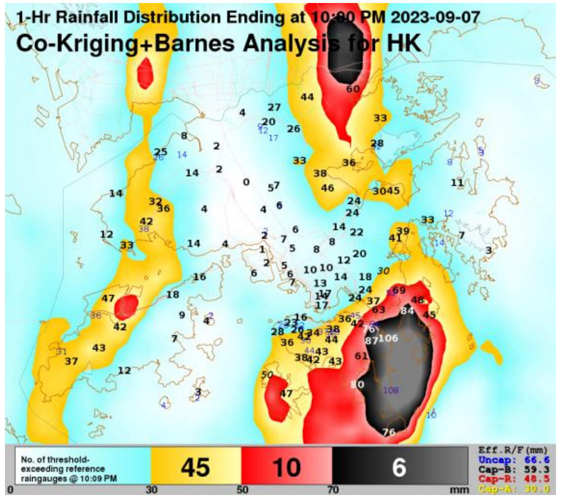
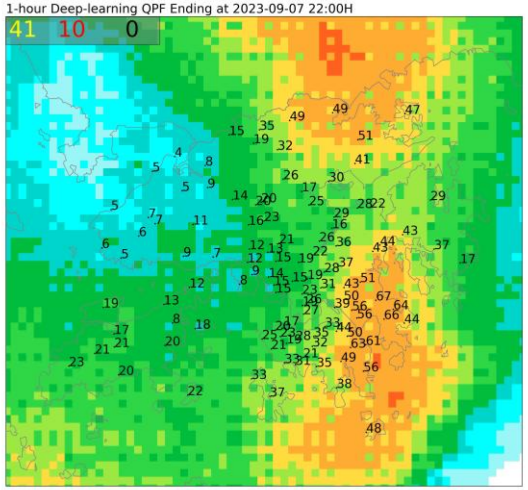
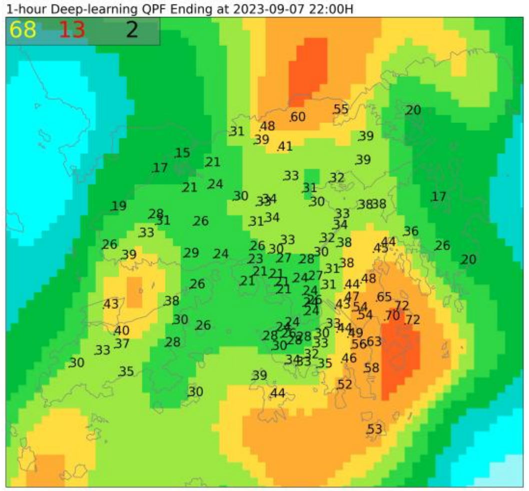
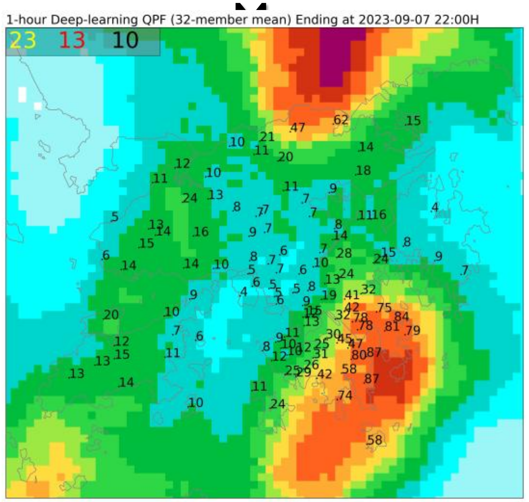
1hr QPF Base time: 2100H

QPE | ResConvLSTM-GAN | Earthformer | Diffusion Ensemble

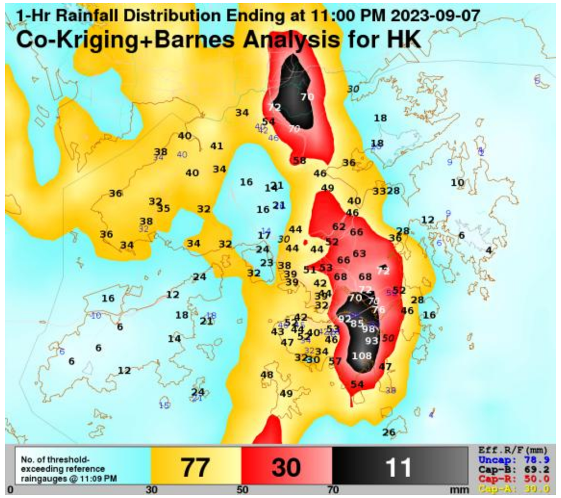


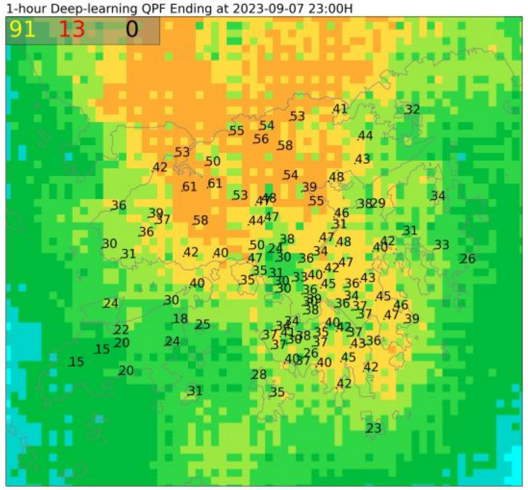


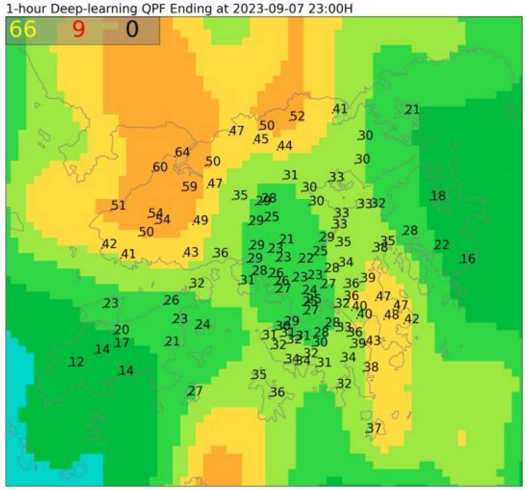


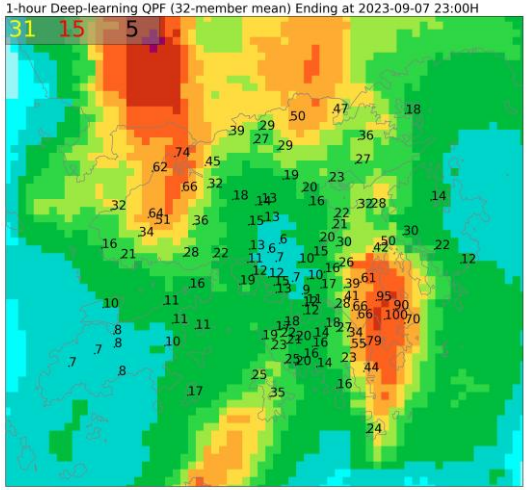


1hr QPF Base time: 2200H









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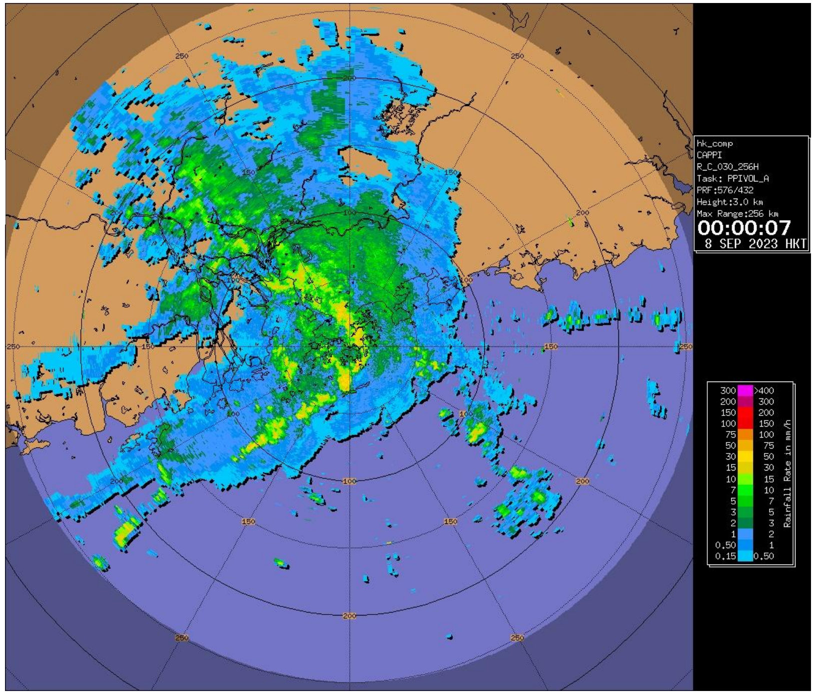

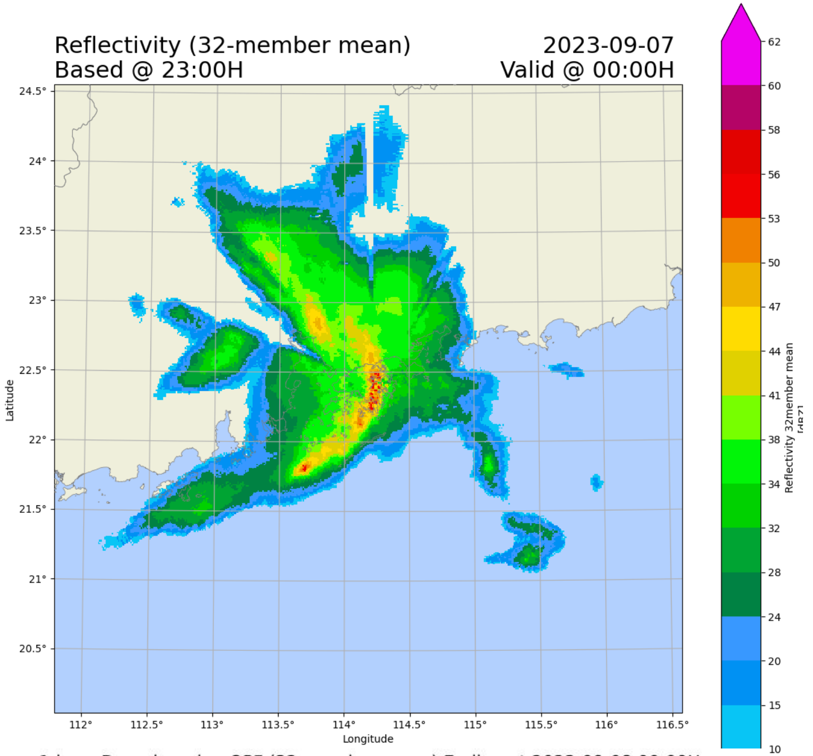

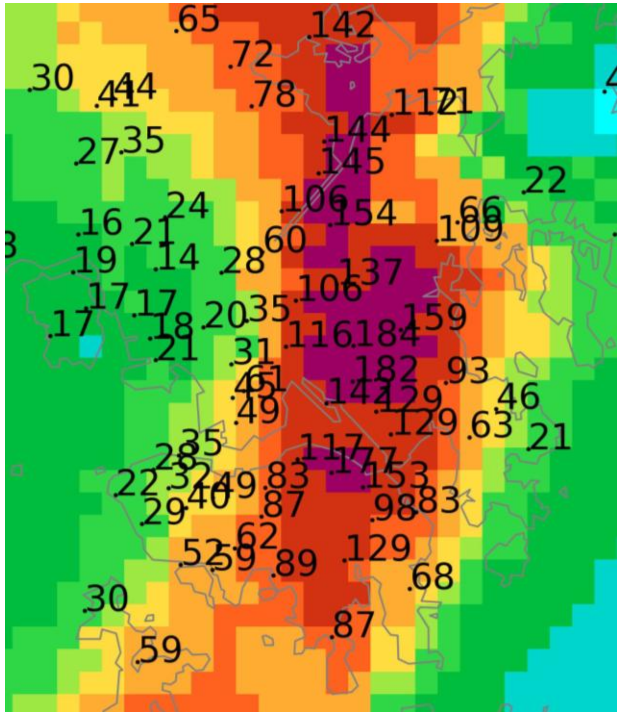

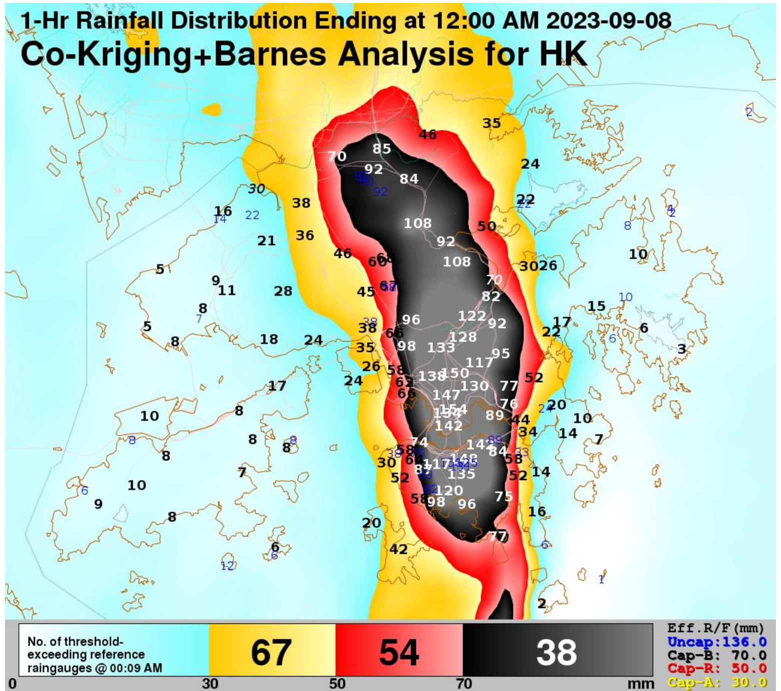

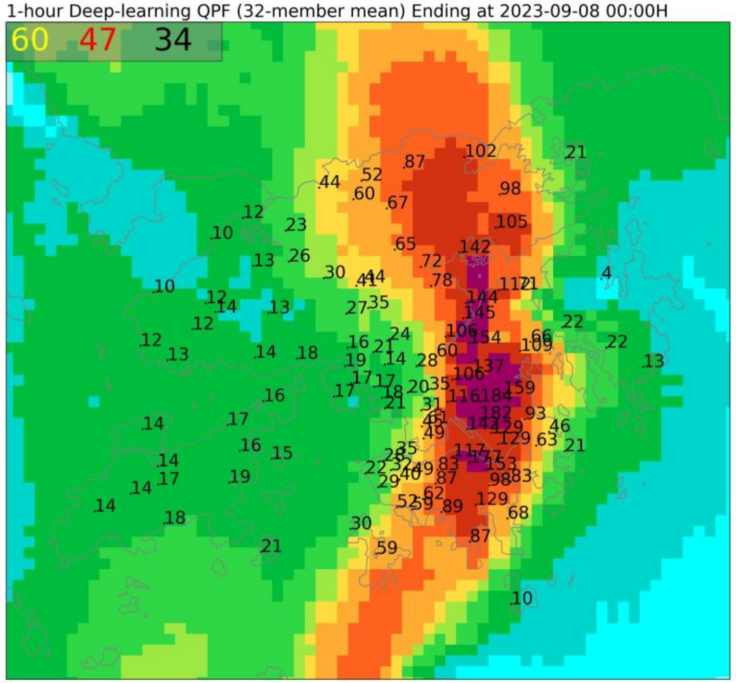

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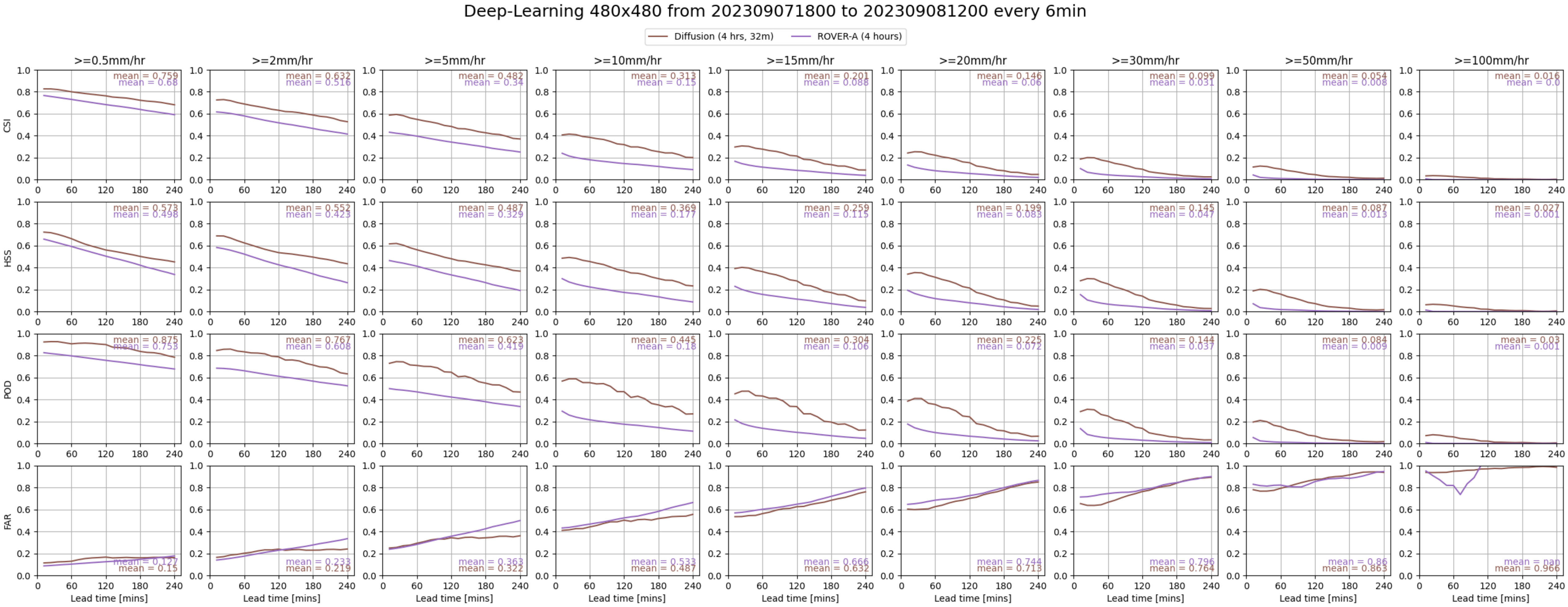
Diffusion (ensemble mean) vs optical flow extrapolation (CSI, HSS, POD, FAR)



0.5 mm/hr	2.0 mm/hr	5.0 mm/hr	10.0 mm/hr	15.0 mm/hr	20.0 mm/hr	30.0 mm/hr	50.0 mm/hr	100.0 mm/hr

T+12 – T+240 minutes

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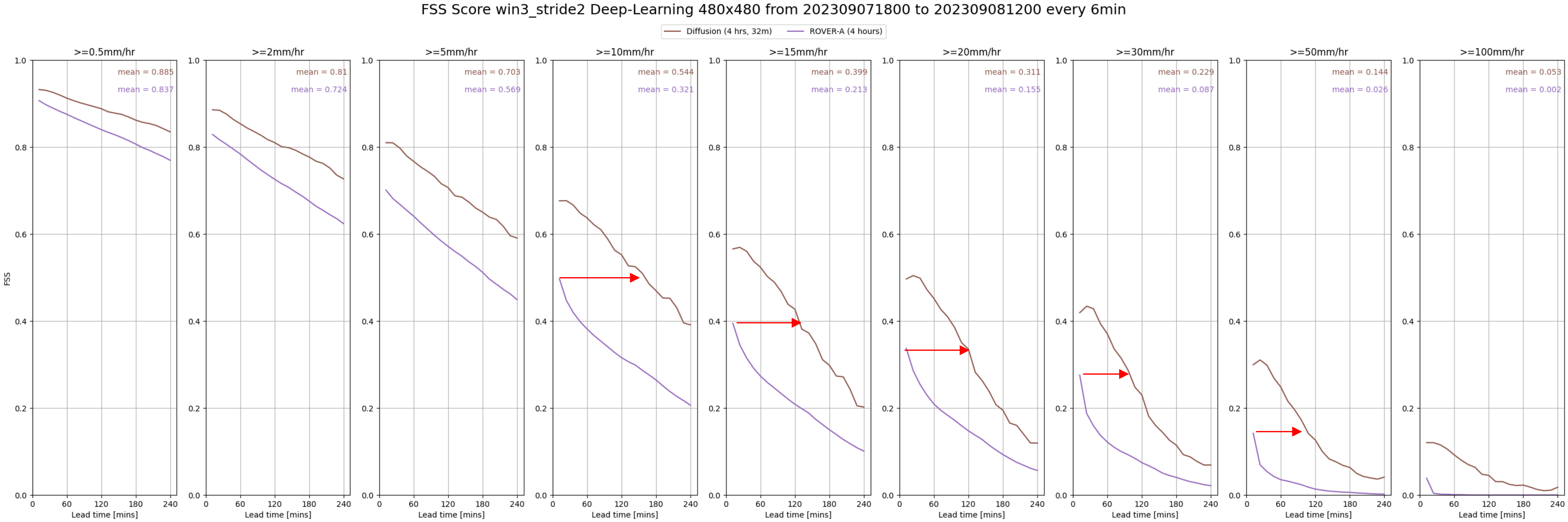
Diffusion (ensemble mean) vs optical flow extrapolation (FSS 3x3 window size)



0.5 mm/hr	2.0 mm/hr	5.0 mm/hr	10.0 mm/hr	15.0 mm/hr	20.0 mm/hr	30.0 mm/hr	50.0 mm/hr	100.0 mm/hr

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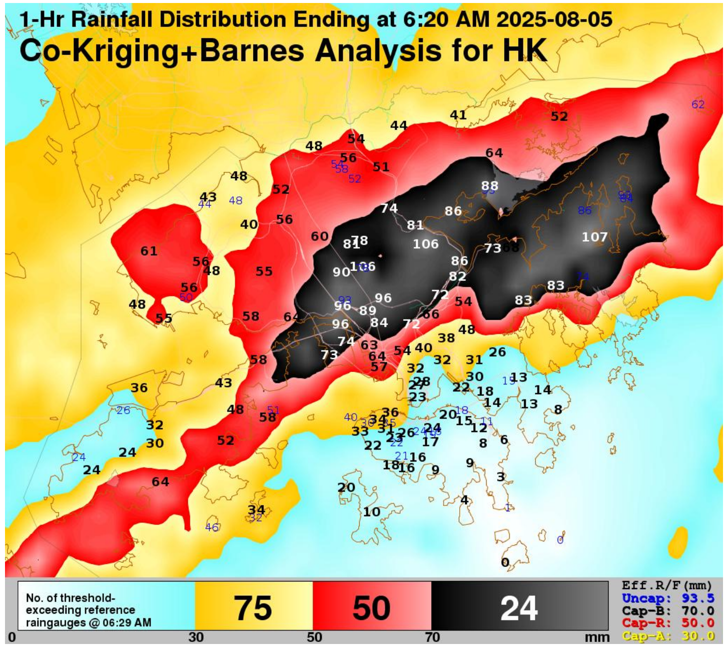
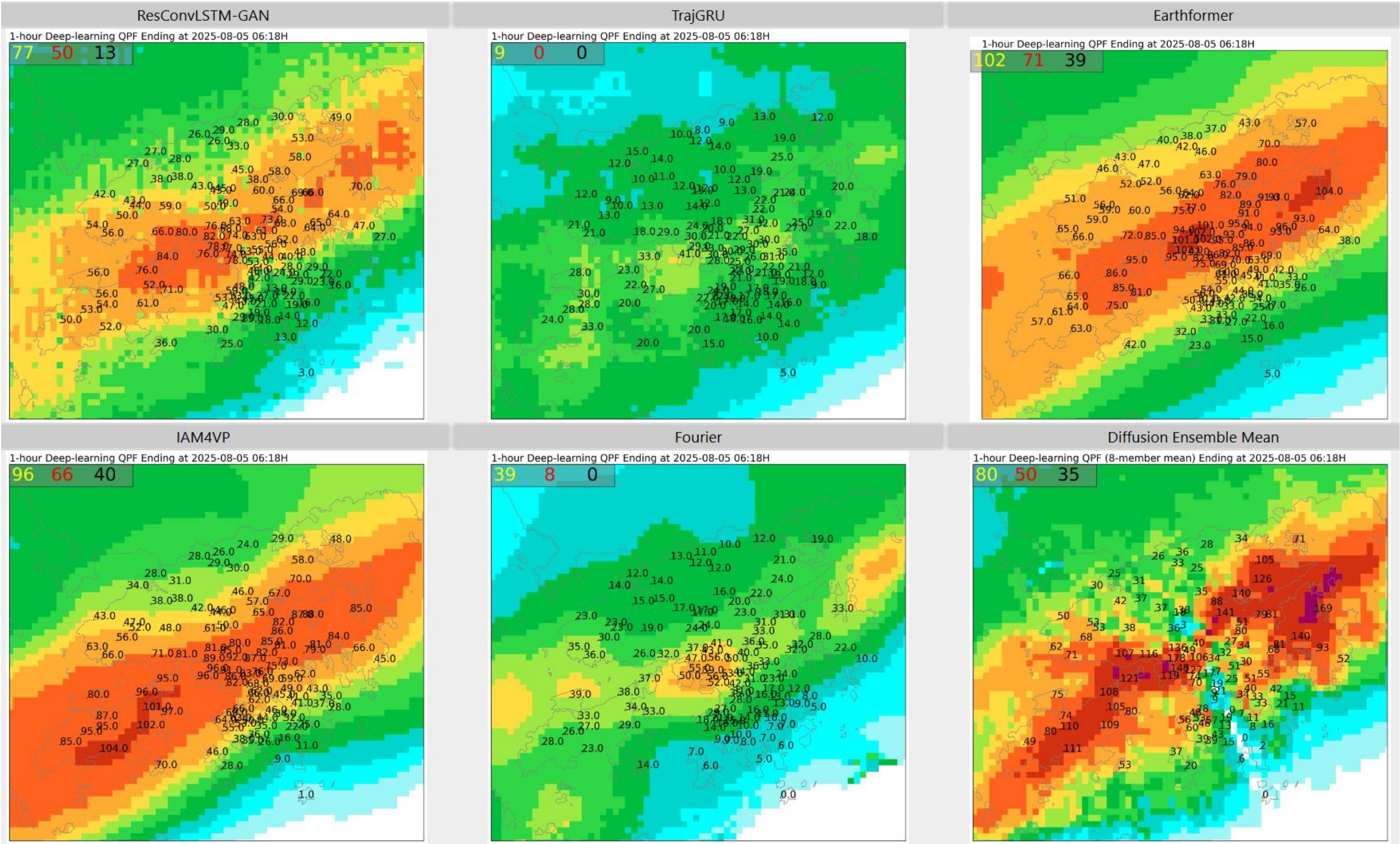
Black Rainstorm on 5 August 2025

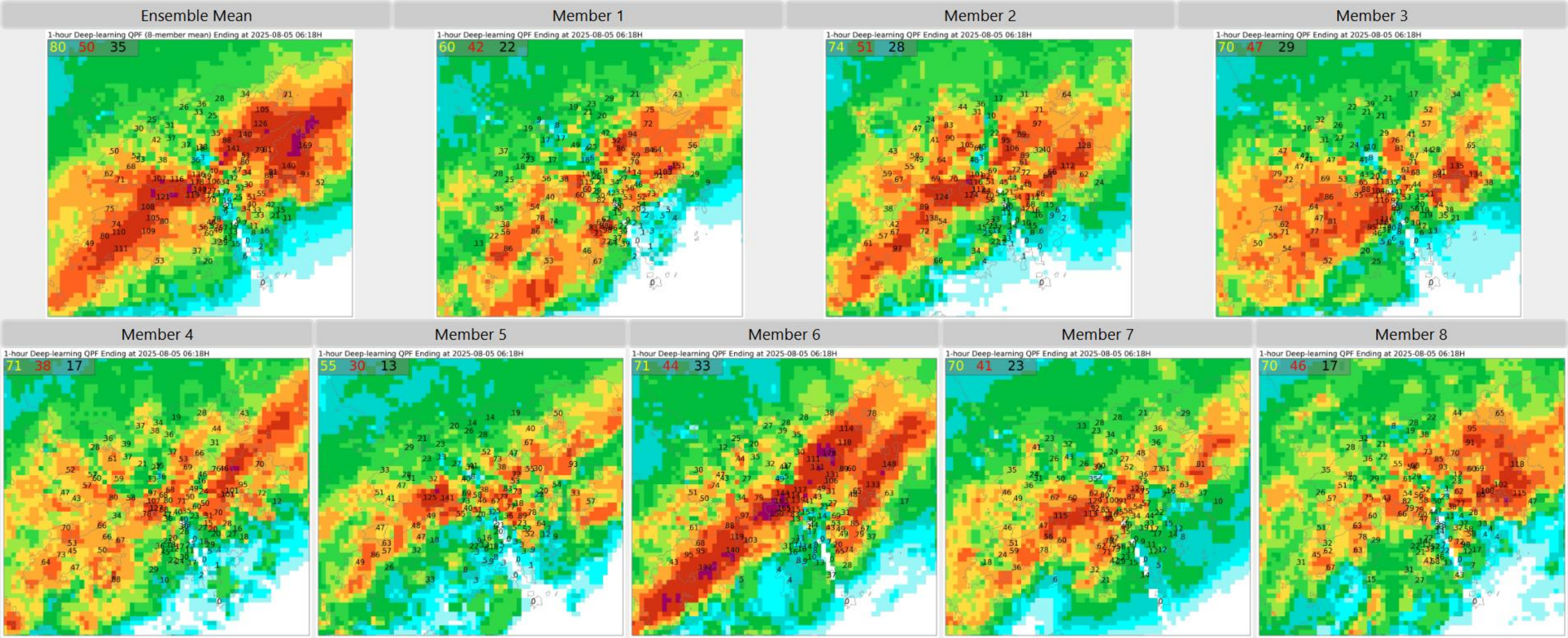
2025-08-05
06:20H





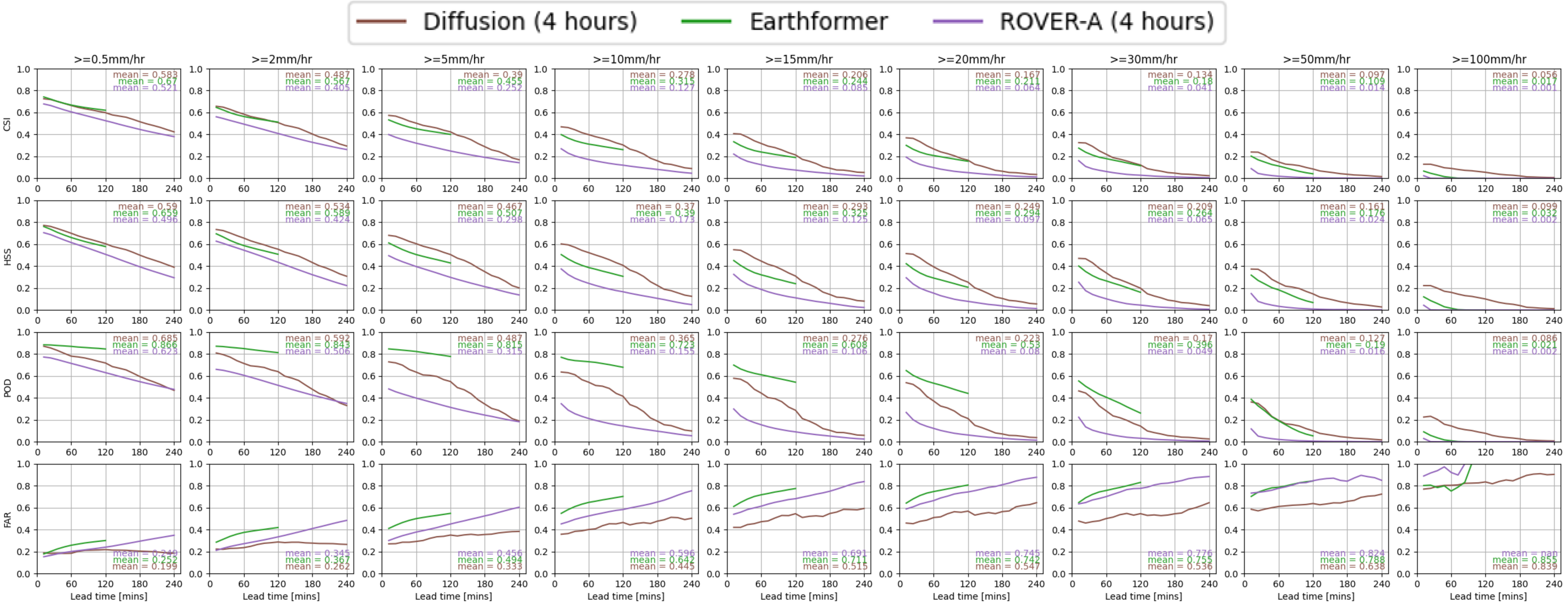
T+1h nowcast from 6 deep learning algorithms

T+1h nowcast from diffusion ensemble mean and 8 members



Verification (4 – 5 Aug 2025) – CSI, HSS, POD, FAR

optical flow vs Earthformer (2 hrs) vs Diffusion ensemble mean



0.5 mm/hr | 2.0 mm/hr | 5.0 mm/hr | 10.0 mm/hr | 15.0 mm/hr | 20.0 mm/hr | 30.0 mm/hr | 50.0 mm/hr | 100.0 mm/hr

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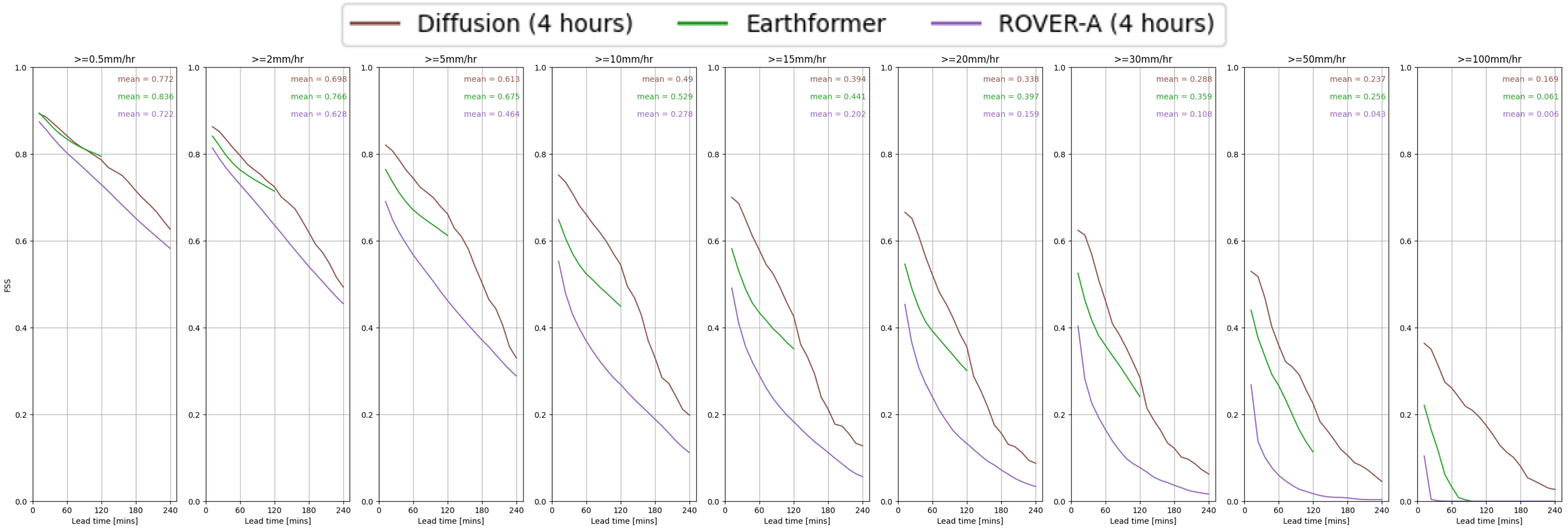
Verification – FSS

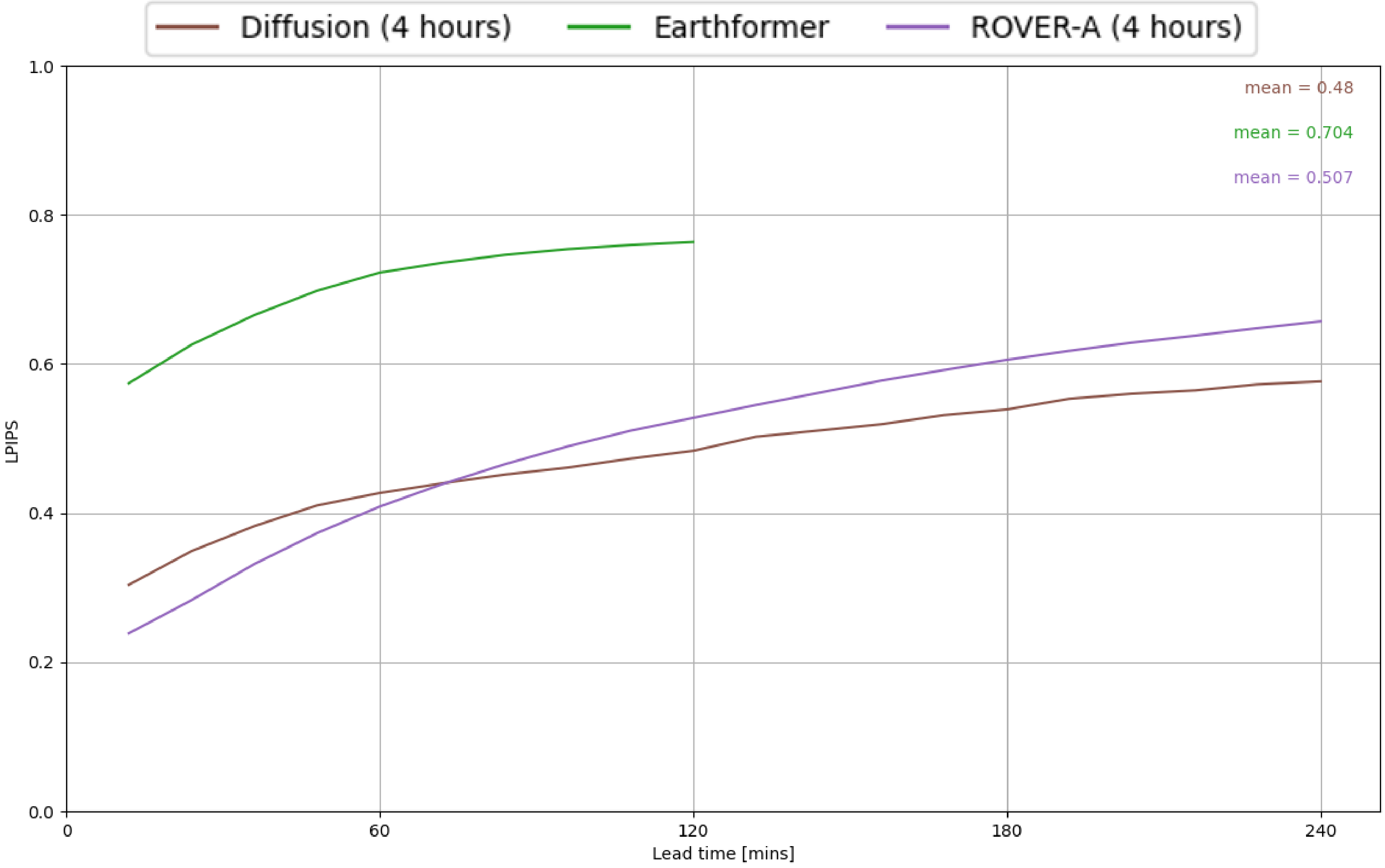
optical flow vs Earthformer (2 hrs) vs Diffusion ensemble mean

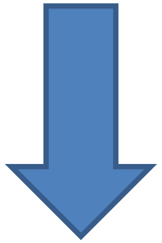


0.5 mm/hr	2.0 mm/hr	5.0 mm/hr	10.0 mm/hr	15.0 mm/hr	20.0 mm/hr	30.0 mm/hr	50.0 mm/hr	100.0 mm/hr

Verification – LPIPS

optical flow vs Earthformer (2 hrs) vs Diffusion ensemble mean





better

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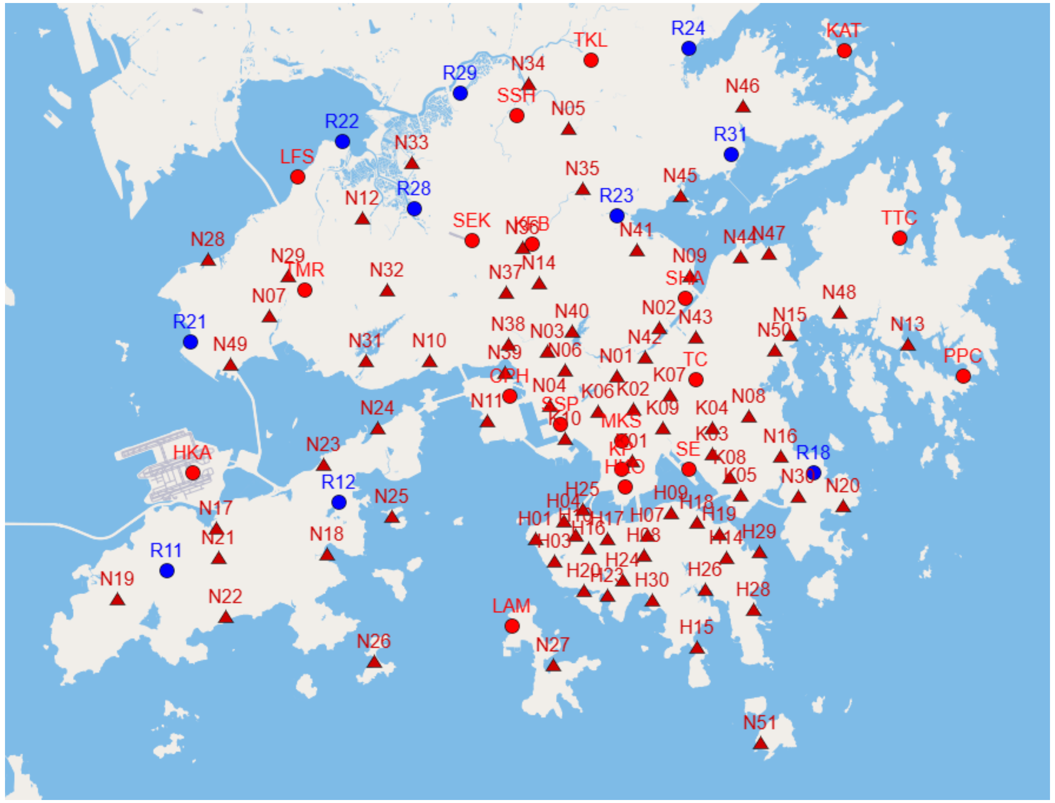
"AI of AI" in improving rainstorm prediction



- Raingauge observations and site-specific QPFs are crucial for assessment and timeliness of issuing rainstorm warnings (Amber / Red / Black)

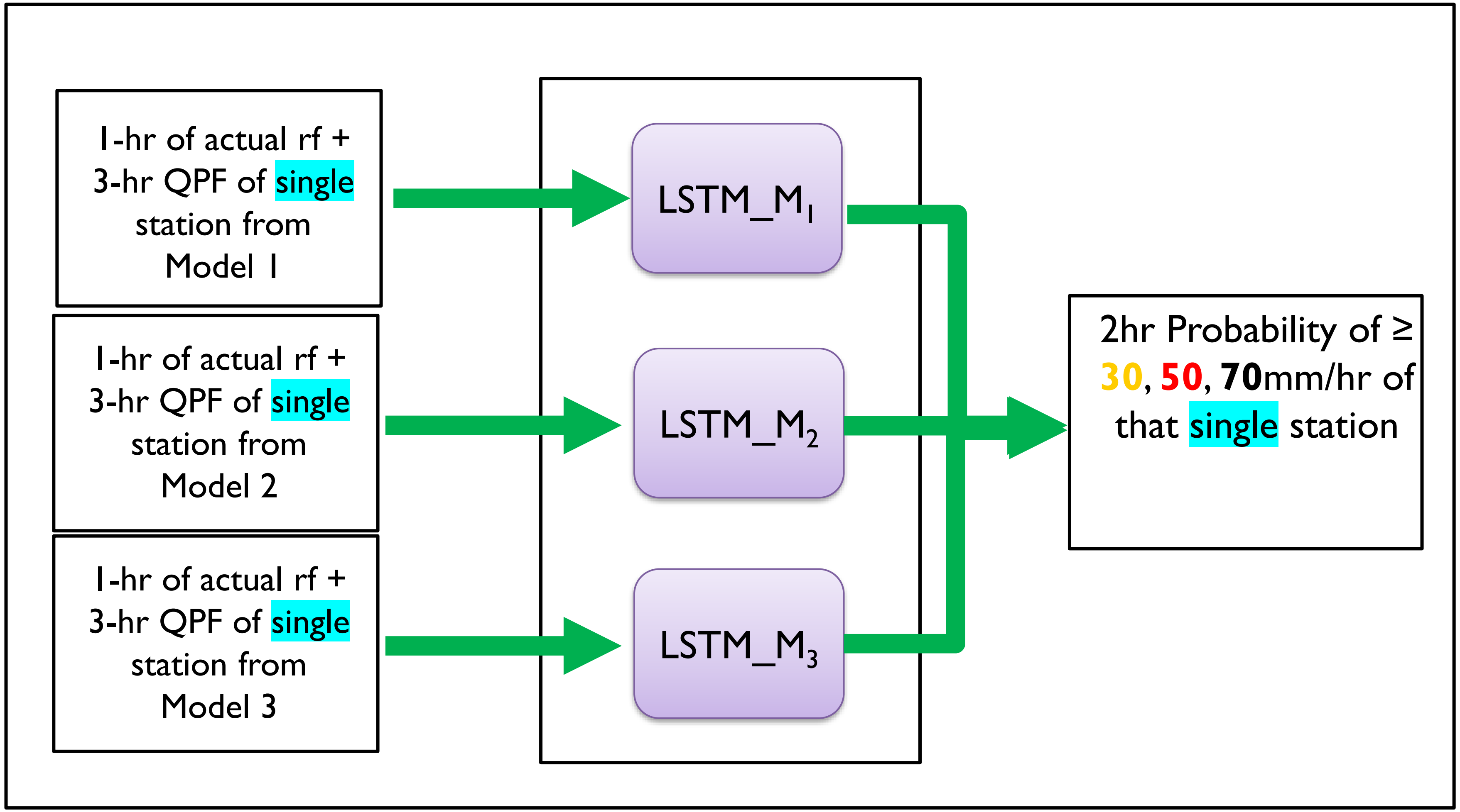
- SWIRLS has been providing a suite of nowcast and "post-processed" rule-based guidance based on optical-flow extrapolation, ensemble based on perturbed optical-flow field, and now into AI models and AI-ensemble being in trial
  - Note they are updated based on 6-minutely radar scan or 1-minute rapid-scan, but available time vary

- Any effective and robust way to integrate all these guidance as a one-stop assessment, rapid-update with minutely rainfall observations?

➔ AI-RAINVIS (Artificial Intelligence Rainstorm Analysis and INtegrated Visuals of SWIRLS)

AI-RAINVIS Model Structure (i)

Universal Station-based Probabilistic Models



***Same** model structure for every station*

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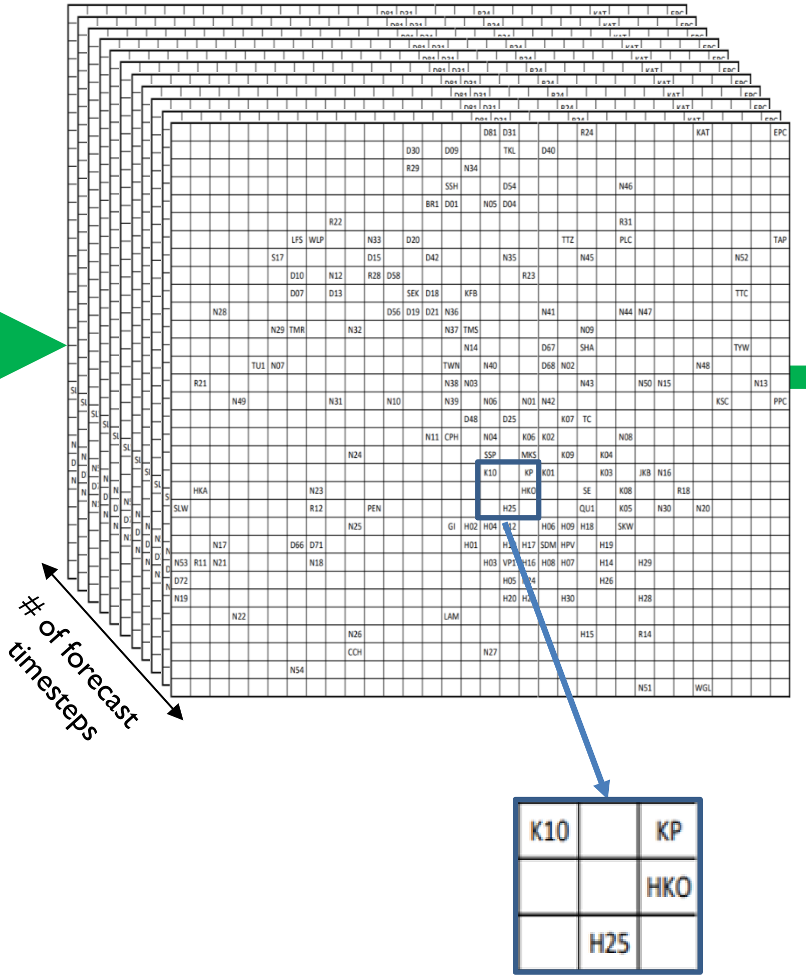
AI-RAINVIS Model Structure (ii)

2hr Probability of ≥ **X** mm/hr in a station

# of stations



Universal Rainstorm Probabilistic Prediction Model

VideoMAE
(Transformer)

Same *model structure for each category of rainstorm warnings X*

2hr Probability of ≥ N stations reach **X** mm/hr

Value of X	Warning
30	Amber
50	Red
70	Black

AI-RAINVIS Web-interface
(Artificial Intelligence Rainstorm Analysis and INtegrated Visuals of SWIRLS)

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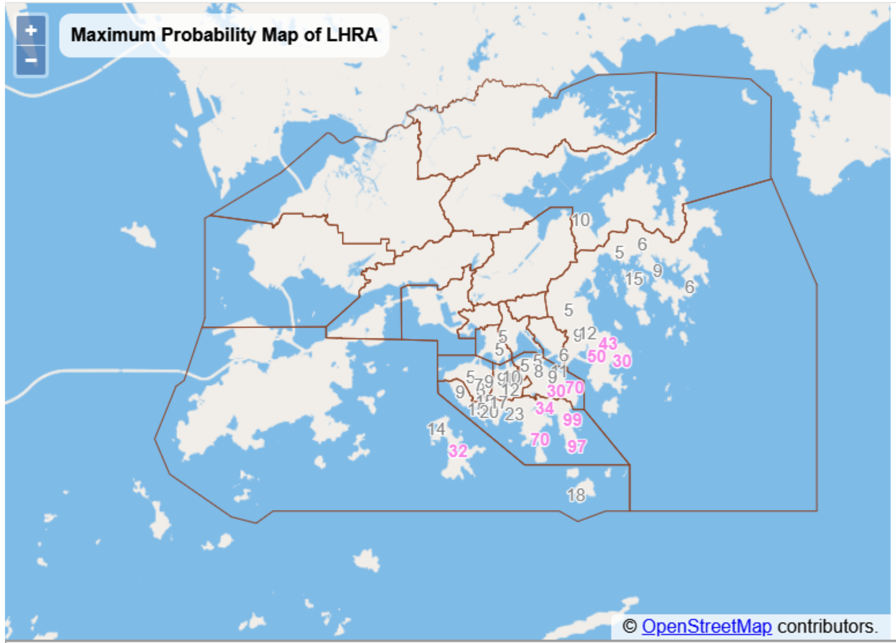
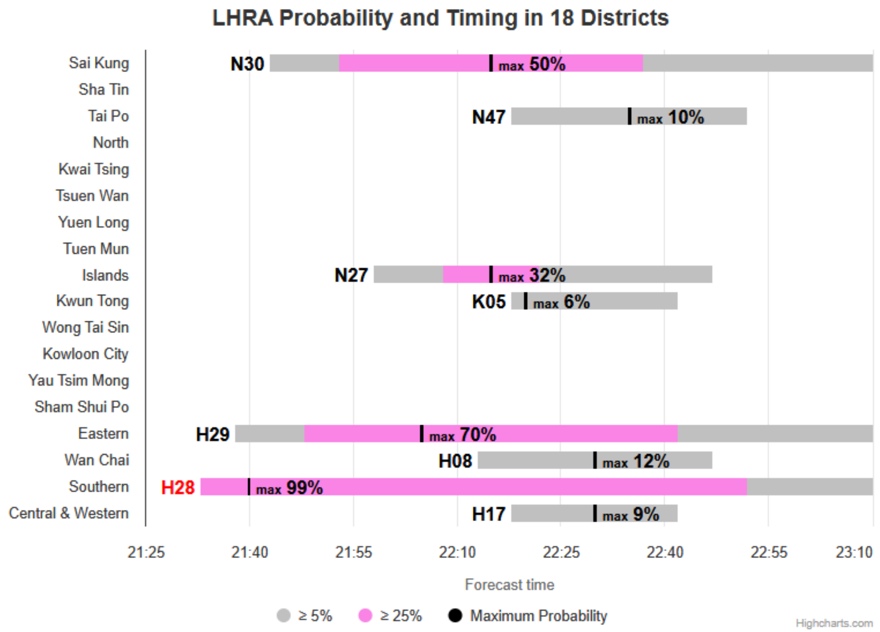




Auto Update:

Heavy Rain Alert Panel:

Include NT Flood Station:

Current time:

202309072135 Submit

AI-RAINVIS Base Time: 2023-09-07 21:30H

1 minute | < | > | latest

User Guide | Presentation

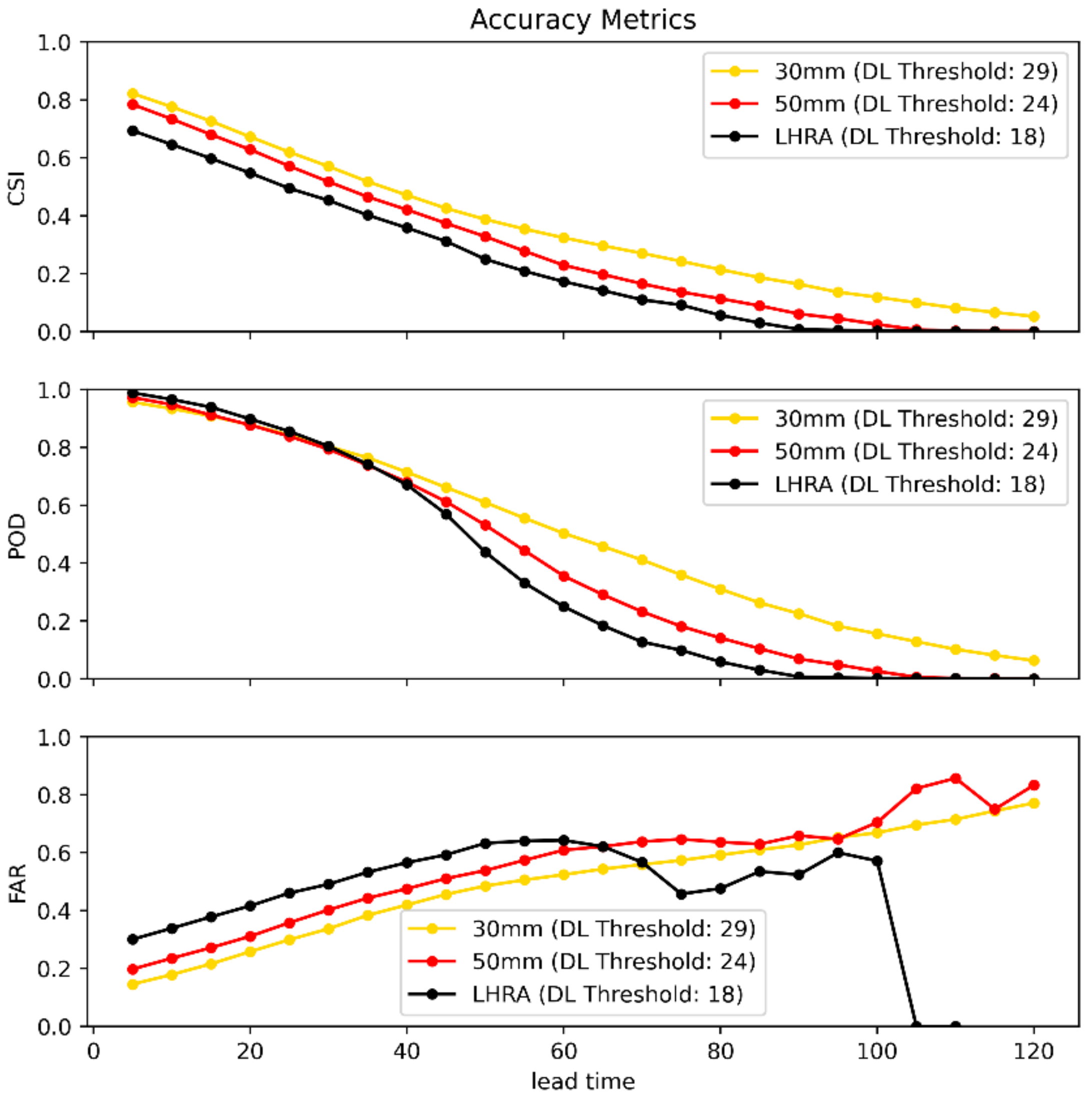
ARROW-HKO:

Date Time	XGBoost-based Prob (Amber)	AI-RAINVIS 1Hr Max	AI-RAINVIS 2Hr Max	Rule-based Prob (Red)	XGBoost-based Prob (Red)	AI-RAINVIS 1Hr Max	AI-RAINVIS 2Hr Max	Rule-based Prob (Black)	XGBoost-based Prob (Black)	AI-RAINVIS 1Hr Max	AI-RAINVIS 2Hr Max	ARROW Max Warning [###]
2023-09-07 21:35	H	99	99	MH	H	94	91	ML	M	9	13	A[M8S]
2023-09-07 21:34	H	99	99	M	MH	95	92	ML	ML	9	11	A[M8S]
2023-09-07 21:33	H	99	99	M	MH	95	92	ML	ML	8	11	A[M8S]
2023-09-07 21:32	H	99	99	M	MH	94	91	ML	ML	7	11	A[M8S]
2023-09-07 21:31	H	99	97	M	M	30	29	ML	ML	0	1	A[M8S]
2023-09-07 21:30	H	99	97	M	M	30	29	ML	ML	0	1	A[M8S]
2023-09-07 21:29	H	99	97	MH	H	29	29	M	ML	0	1	A[M8S]
2023-09-07 21:28	H	99	96	MH	H	29	29	M	ML	0	1	A[M8S]
2023-09-07 21:27	H	98	96	MH	H	28	28	M	ML	0	1	A[M8S]
2023-09-07 21:26	H	98	95	MH	H	27	28	M	ML	0	1	A[M8S]
2023-09-07 21:25	H	99	98	MH	H	54	54	M	ML	2	4	A[M8S]

Minutely update probabilistic assessments from different available nowcasting tools with raingauge observations at the time

Amber | Red | Black

AI-RAINVIS Verification



Prob	CSI	Lead time [25/50/75p in min]		
Amber (MH)	0.257	22	44	65
Red (MH)	0.537	39	61	81
Black (MH)	0.450	53	68	84
Black (H)	0.521	0	3	25

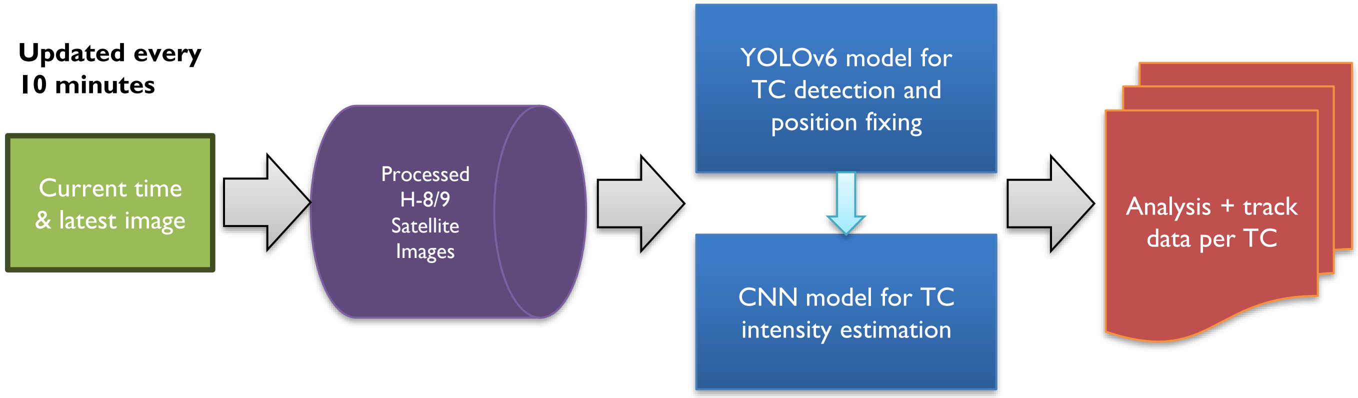
Verification against actual # of raingauges reaching Amber/Red/Black level when respective probability category is met

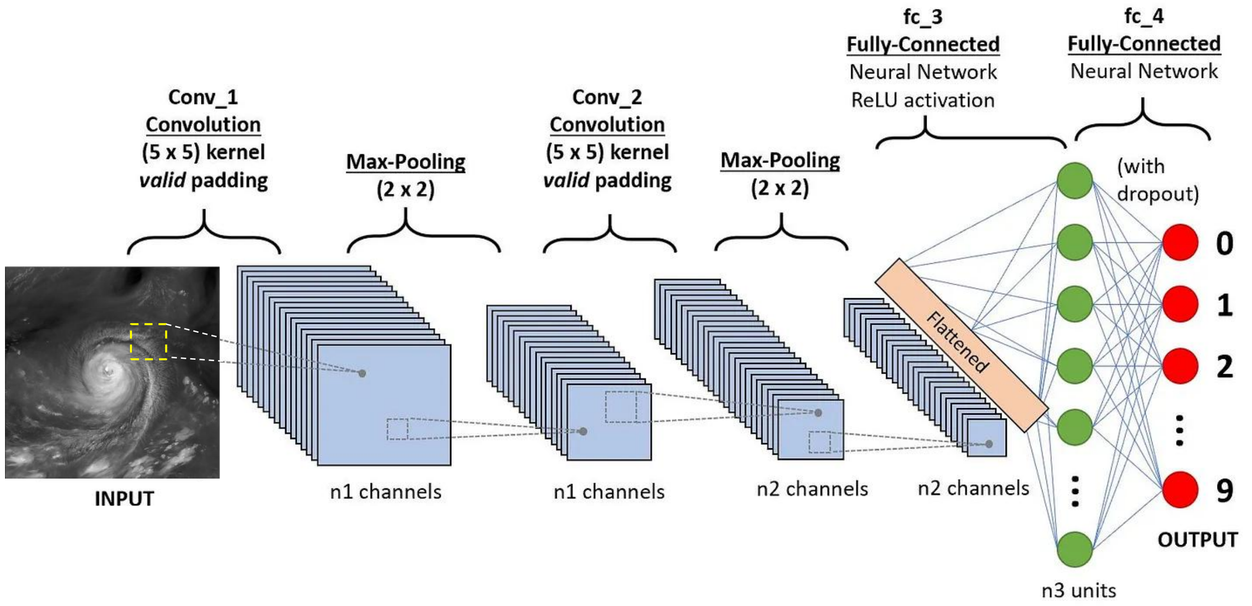
Way forward on AI Nowcast Support

- Deep learning nowcast algorithms
  - More efficient diffusion based technique (spatio-temporal latent diffusion) to speed up training and inference
  - Enhancement of satellite-based reflectivity and rainfall nowcasts (Earthformer, diffusion)
  - Physics constraints and inputs from NWP / AIWP
- “AI of AI” approach to add values
  - Extend ML technique to LLM (or SLM/VLM for specific high impact convective weather or site-specific assessments)
- AI-based automatic tropical cyclone detection and intensity analysis
- Regional collaboration on AI nowcasting techniques

AI in Tropical Cyclone Analysis and Nowcast

- **AI-STORMVIS**
  - **AI**-driven **S**atellite-based **T**C **O**bject **R**ecognition, **M**otion **V**isualisation and **I**ntensity estimation **S**ystem
  - TC detection and position fixing
    - **Y**ou **O**nly **L**ook **O**nce (YOLO) small object detection model
    - Ensemble detection models
  - TC intensity estimation
    - Convolutional neural network (CNN)
  - Visualisation web-based platform





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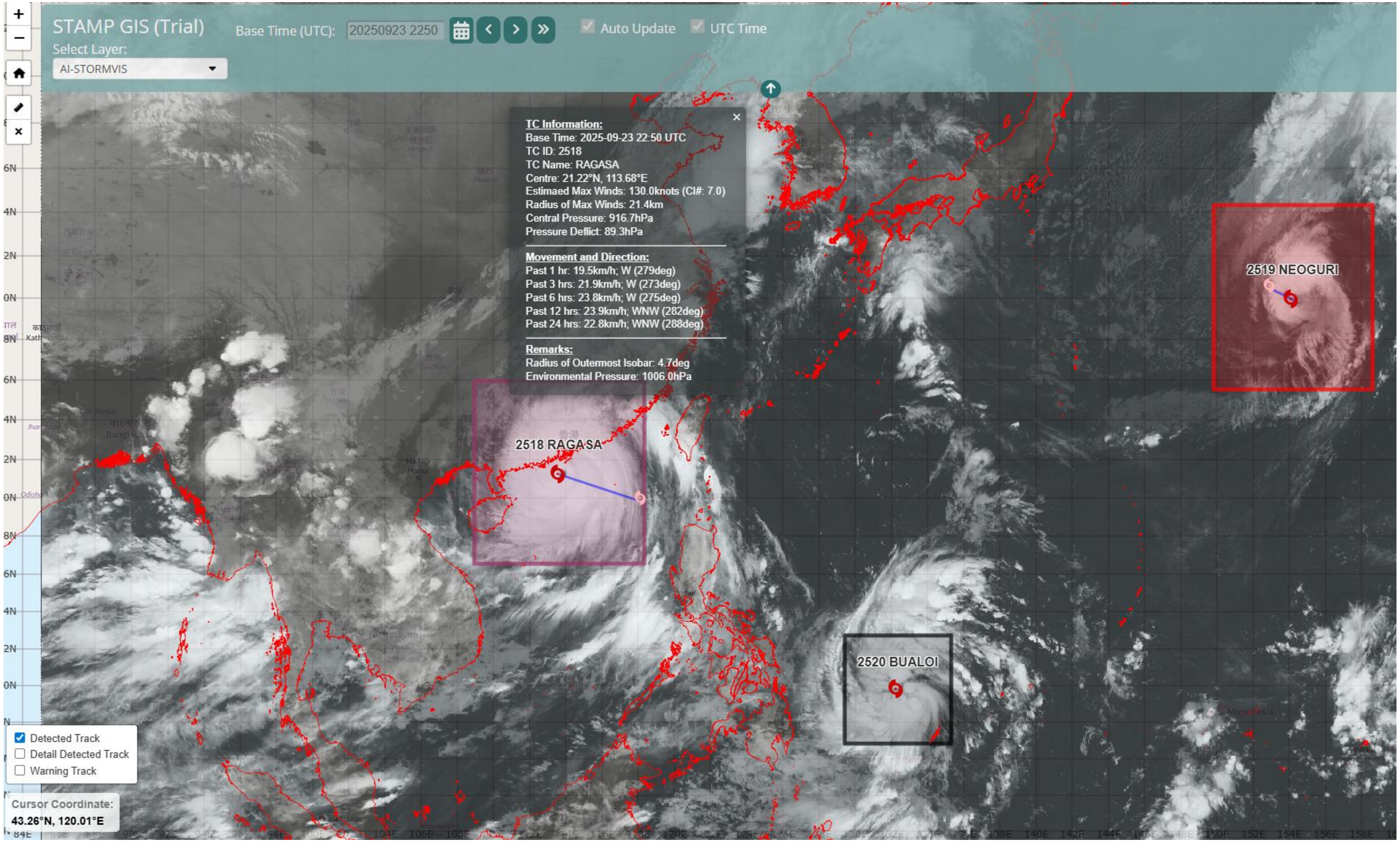
RSMC for Nowcasting
WMO

AI-STORMVIS on RSMC website (under trial)



ESCAP/WMO Typhoon Committee

ESCAP

WORLD METEOROLOGICAL ORGANIZATION

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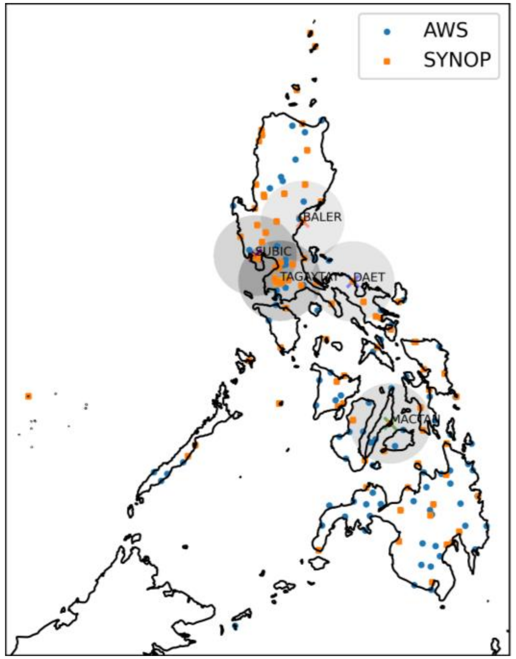
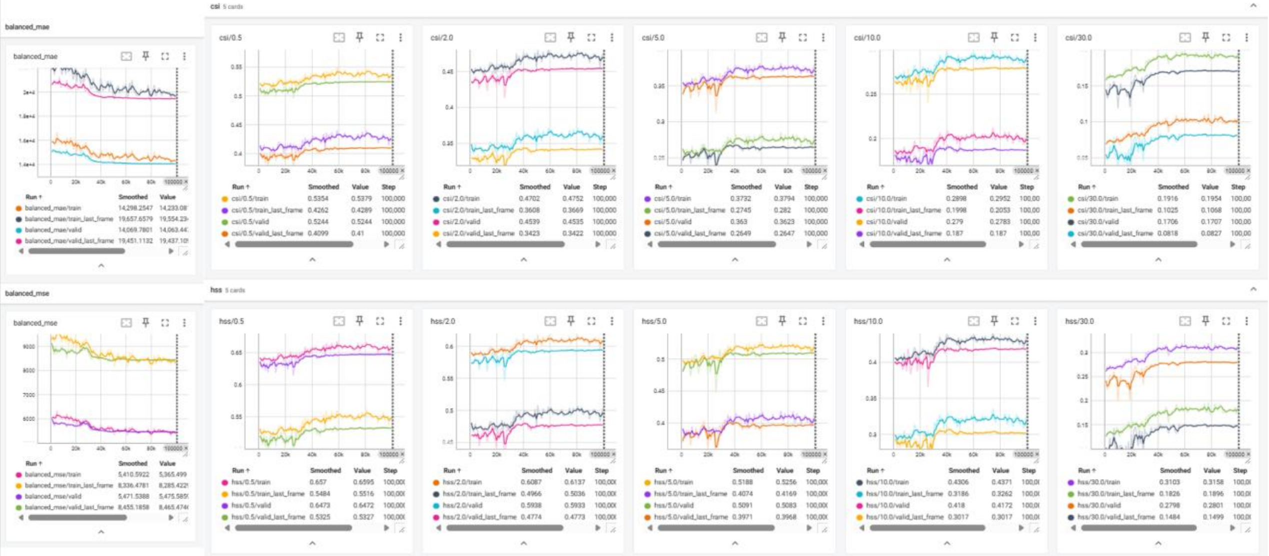
WMO 臨近預報區域專業氣象中心 RSMC for Nowcasting

Collaboration with **PAGASA** and **TMD** in knowledge transfer and implementing Com-SWIRLS and deep learning nowcast models

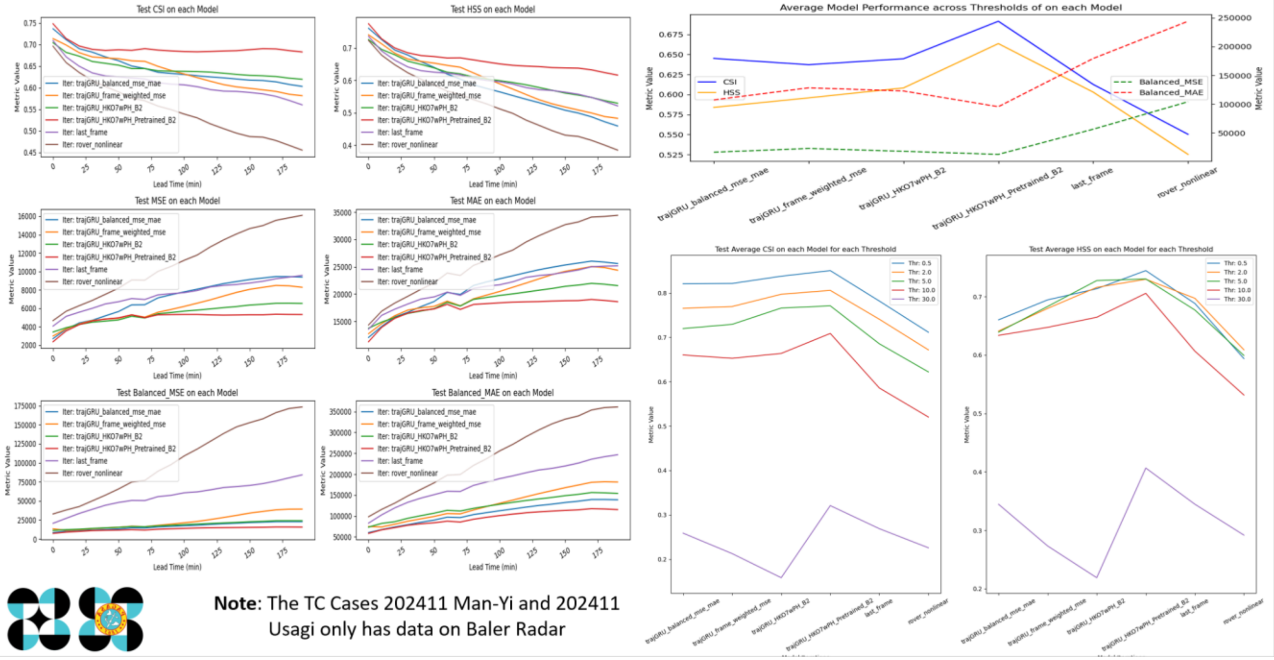


Model Training: TrajGRU with Pretraining, Individual Radars



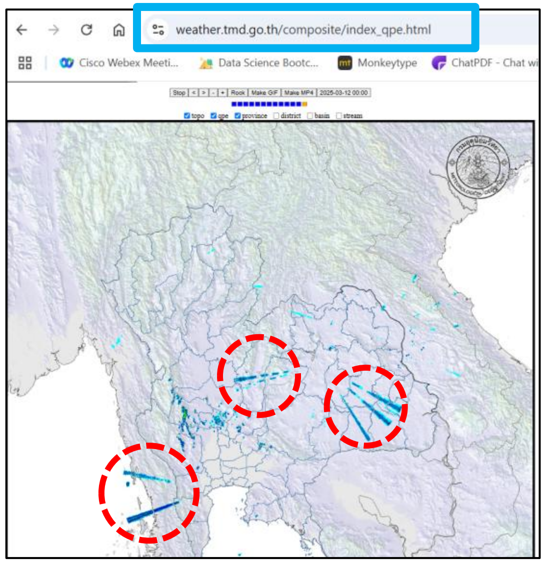
Model Training Lasted 5.254 days at 100,000 iterations

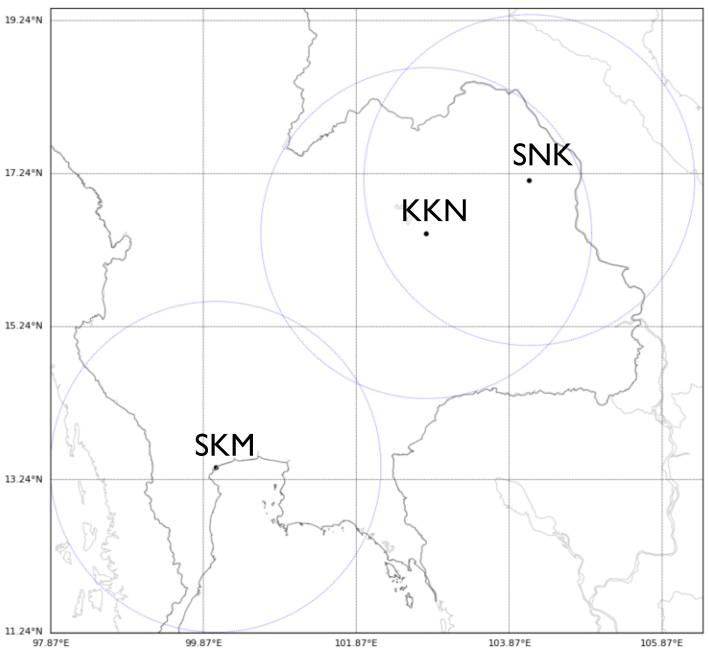
Model Evaluation – Test TC Data

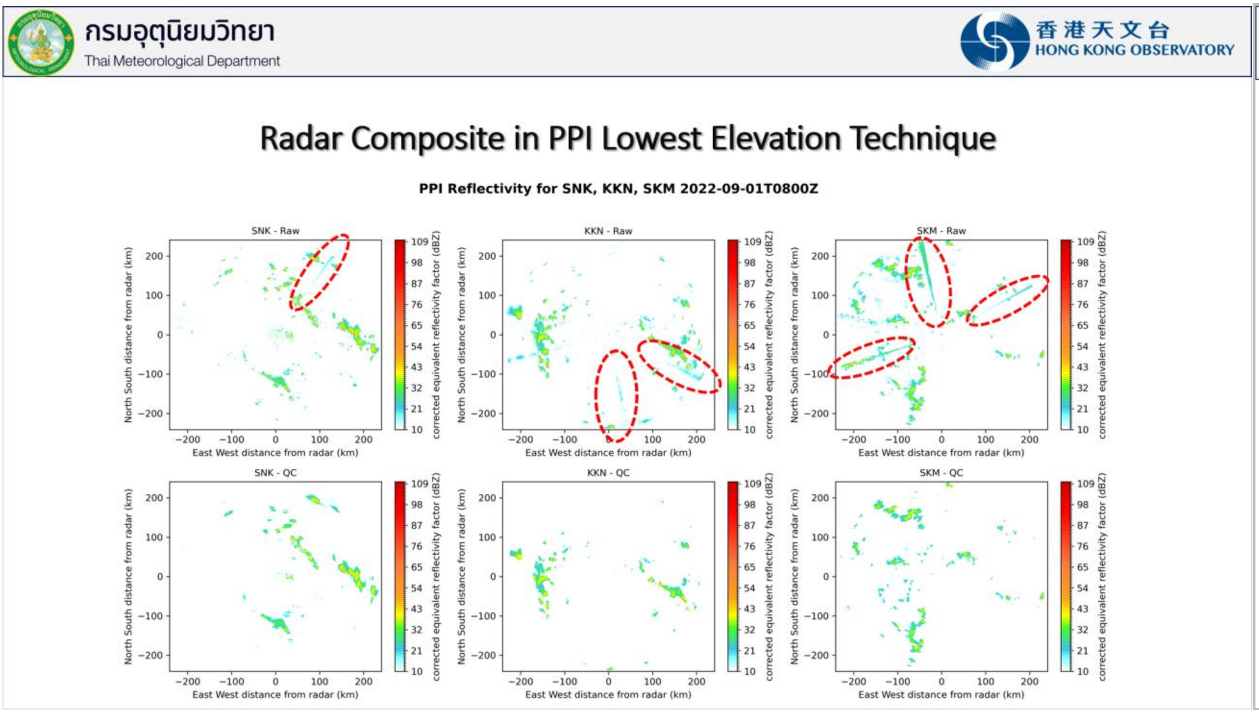


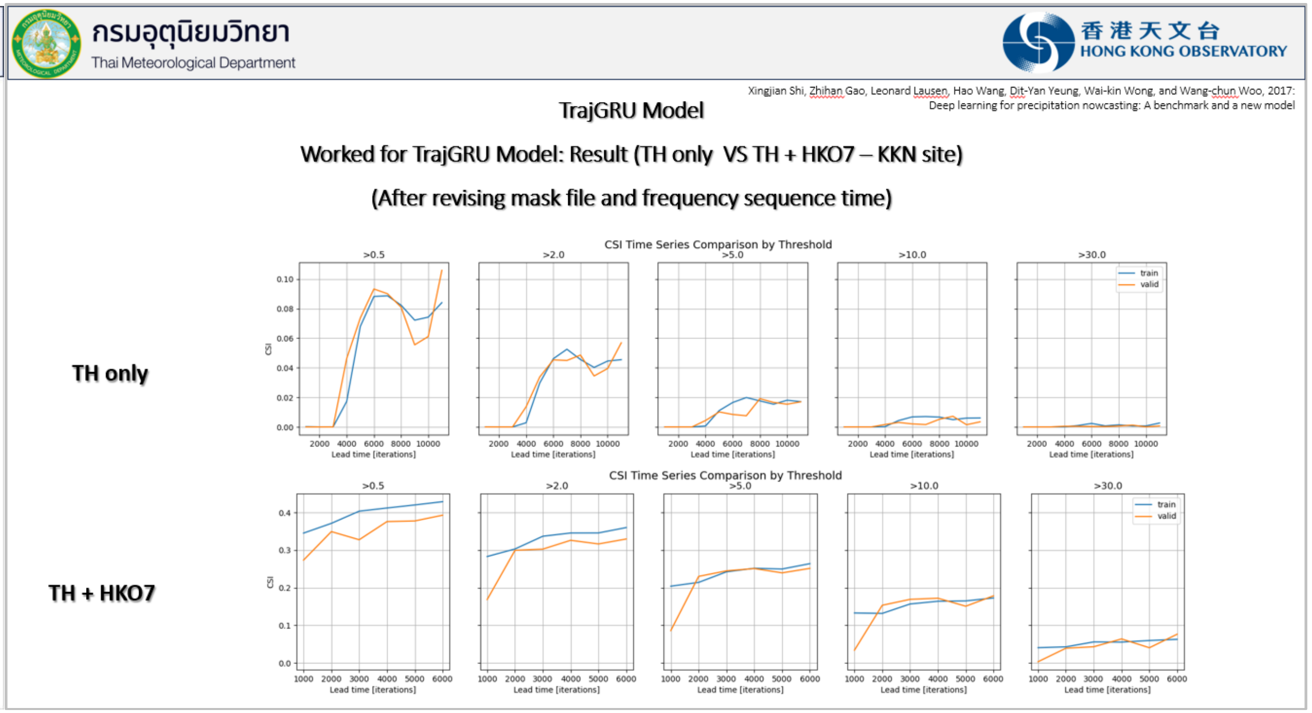
Note: The TC Cases 202411 Man-Yi and 202411 Usagi only has data on Baler Radar

Collaboration with **PAGASA** and **TMD** in knowledge transfer and implementing Com-SWIRLS and deep learning nowcast models









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Thank you very much