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HONG KONG OBSERVATORY

A NEW DEEP LEARNING NOWCAST MODEL OF RADAR IMAGERY USING GENERATIVE ADVERSARIAL NETWORK FOR OPERATIONAL RAINFALL NOWCASTING

AMS 40th Conference on Radar Meteorology

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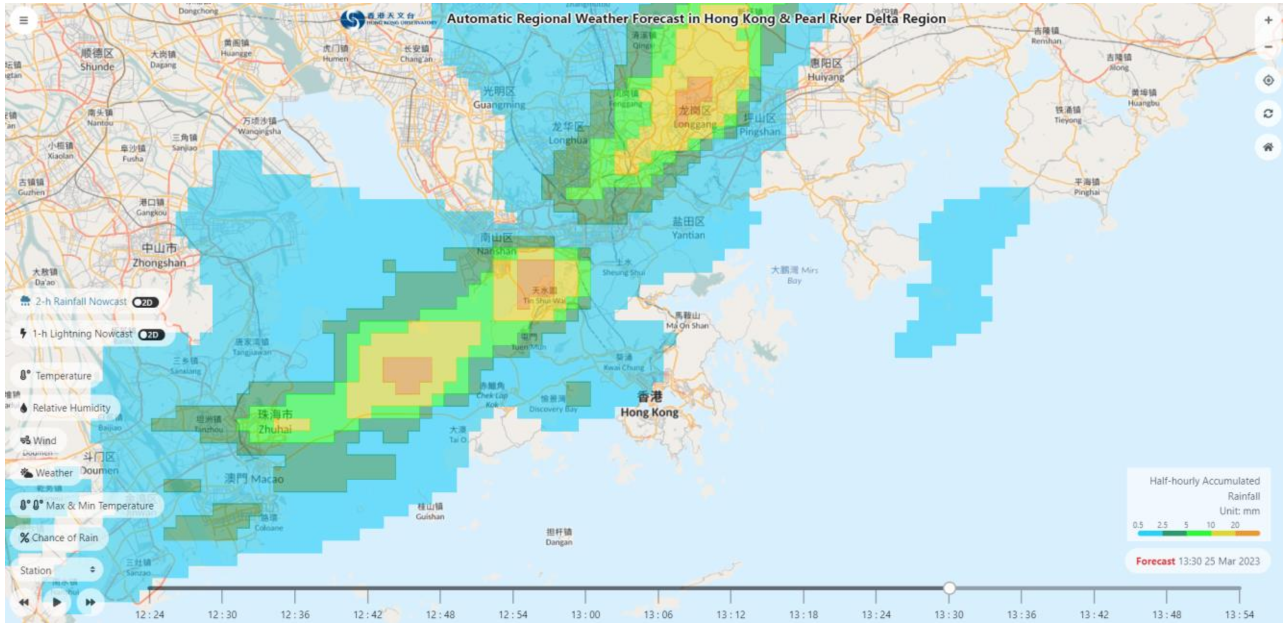
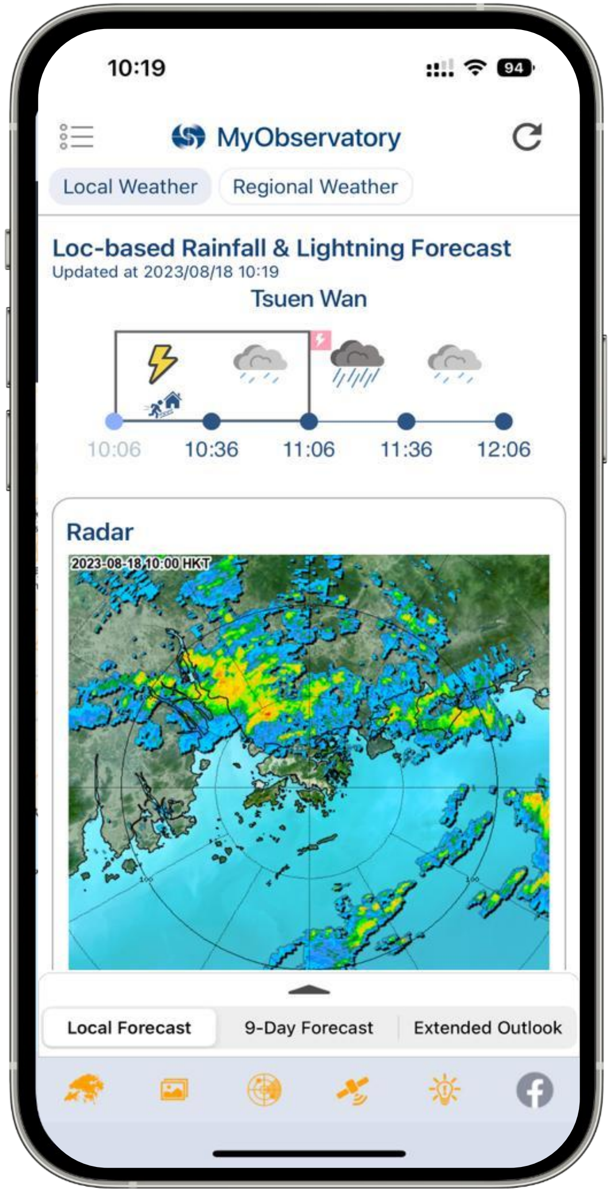
Our Nowcasting Service to the Public:



Web-based 2-hour Rainfall and 1-hour Lightning Nowcast over the Pearl River Delta Region



Location-based Nowcast via MyObservatory Mobile App

Severe Weather Warnings

Need a high-resolution and accurate rainfall nowcast algorithm

Past Development on AI Rainfall Nowcast:

Convolutional LSTM Network: A Machine Learning Approach for Precipitation Nowcasting

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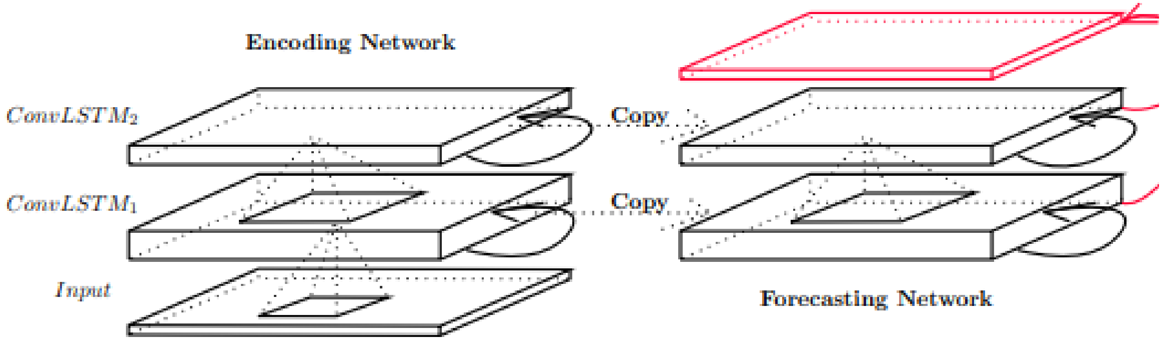

Figure 3: Encoding-forecasting ConvLSTM network for precipitation nowcasting

Deep Learning for Precipitation Nowcasting: A Benchmark and A New Model

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Department of Computer Science and Engineering
Hong Kong University of Science and Technology
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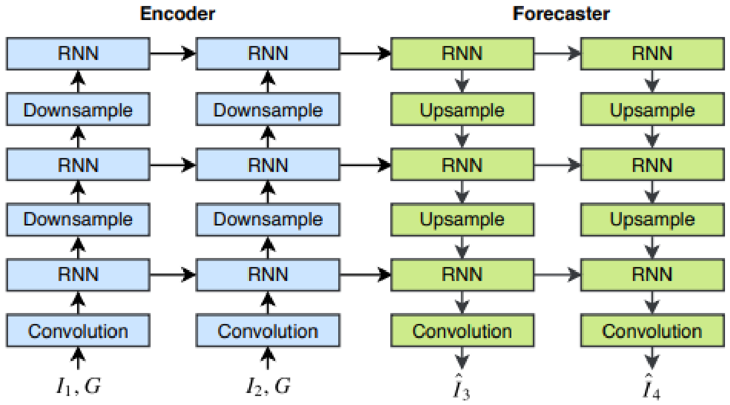
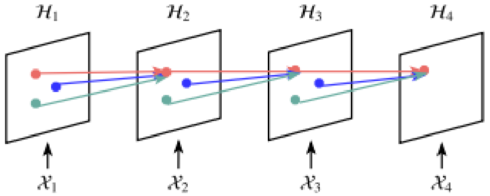
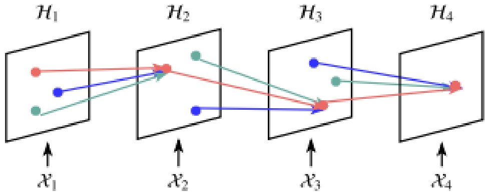


Figure 1: Example of the encoding-forecasting structure used in the paper. In the figure, we use three RNNs to predict two future frames $\hat{I}_3, \hat{I}_4$ given the two input frames I_1, I_2. The spatial coordinates G are concatenated to the input frame to ensure the network knows the observations are from different locations. The RNNs can be either ConvGRU or TrajGRU. Zeros are fed as input to the RNN if the input link is missing.



(a) For convolutional RNN, the recurrent connections are fixed over time.



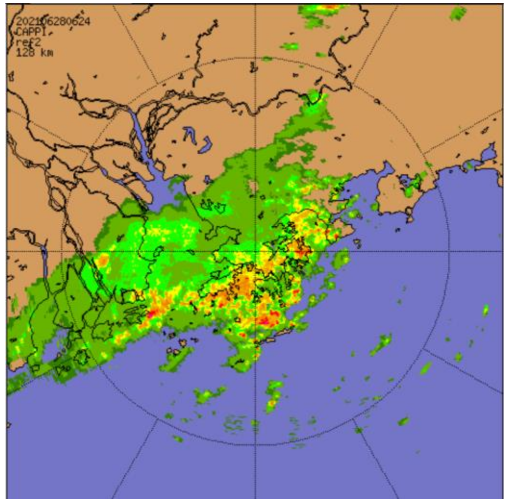
(b) For trajectory RNN, the recurrent connections are dynamically determined.

Figure 2: Comparison of the connection structures of convolutional RNN and trajectory RNN. Links with the same color share the same transition weights. (Best viewed in color)

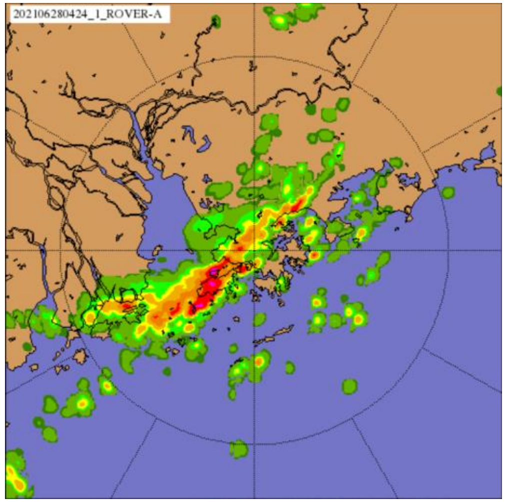
A Quick Comparison of Rainfall Nowcast Methods

2-hour Rainfall Nowcast

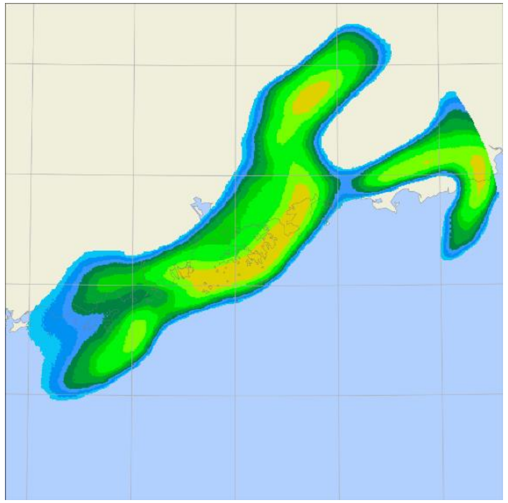
Actual



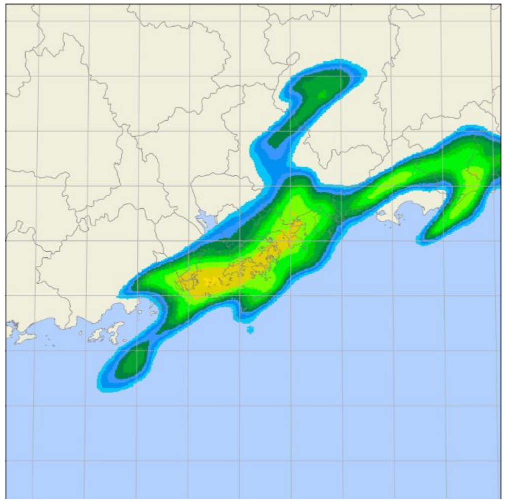
Optical flow (ROVER)



ConvLSTM



TrajGRU



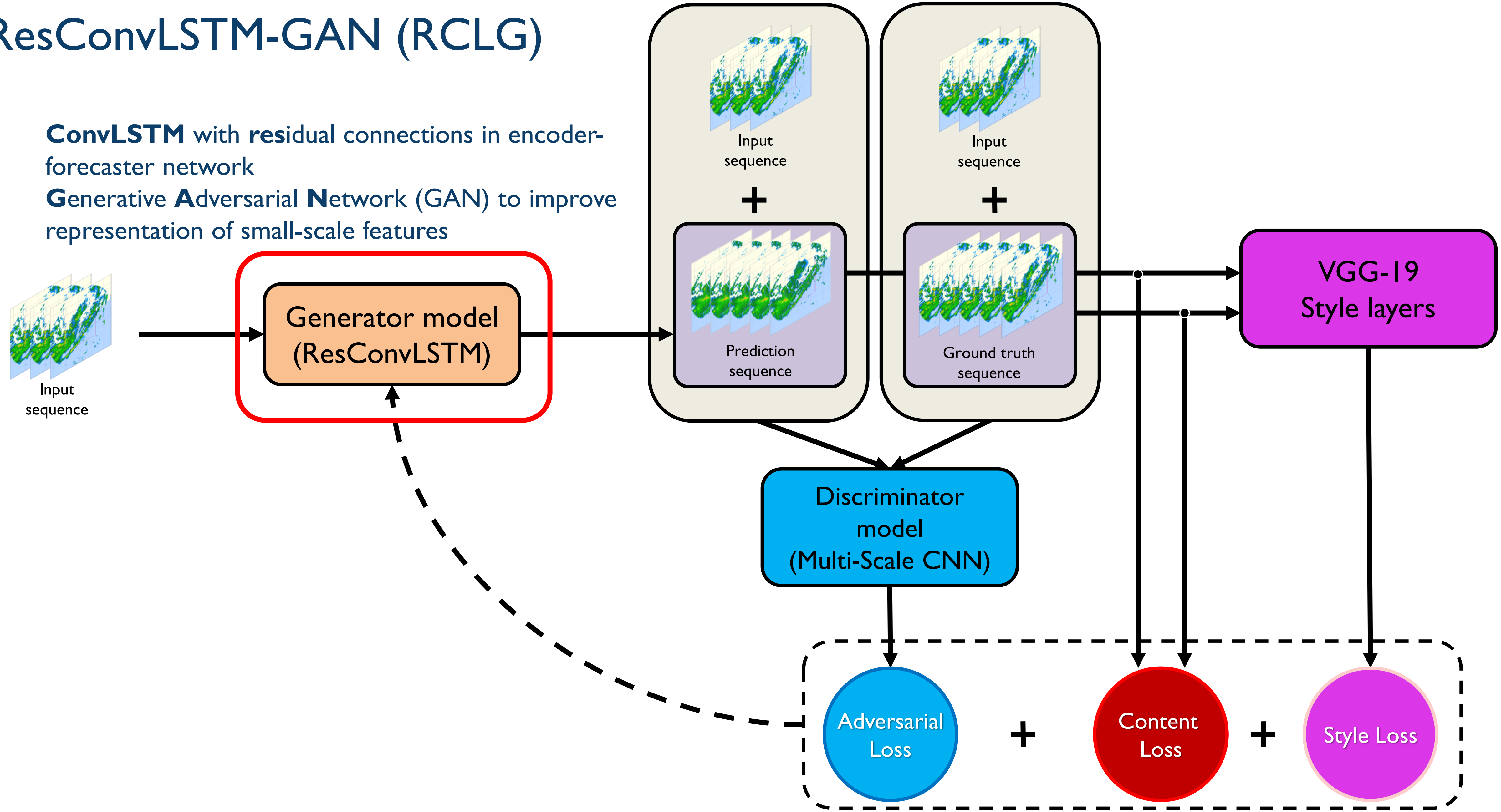
AI Methods:

- ☺ Movement Prediction, Intensity Evolution
- ☹ Blurring Problem = Reduced Resolution
- ⇨ Inefficient in Nowcast Operation

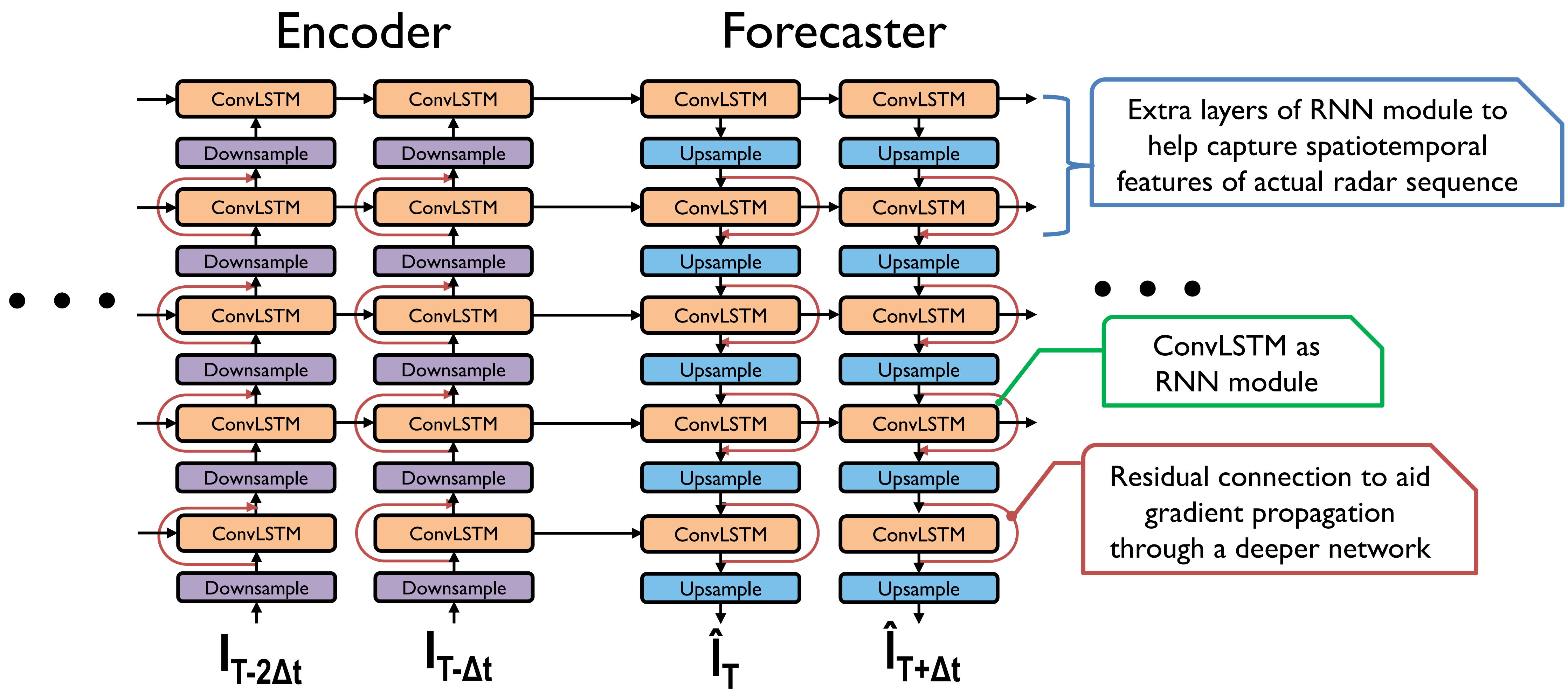
⇨ Need a Better Model & Loss Function

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



Generator: ResConvLSTM



ResConvLSTM-GAN

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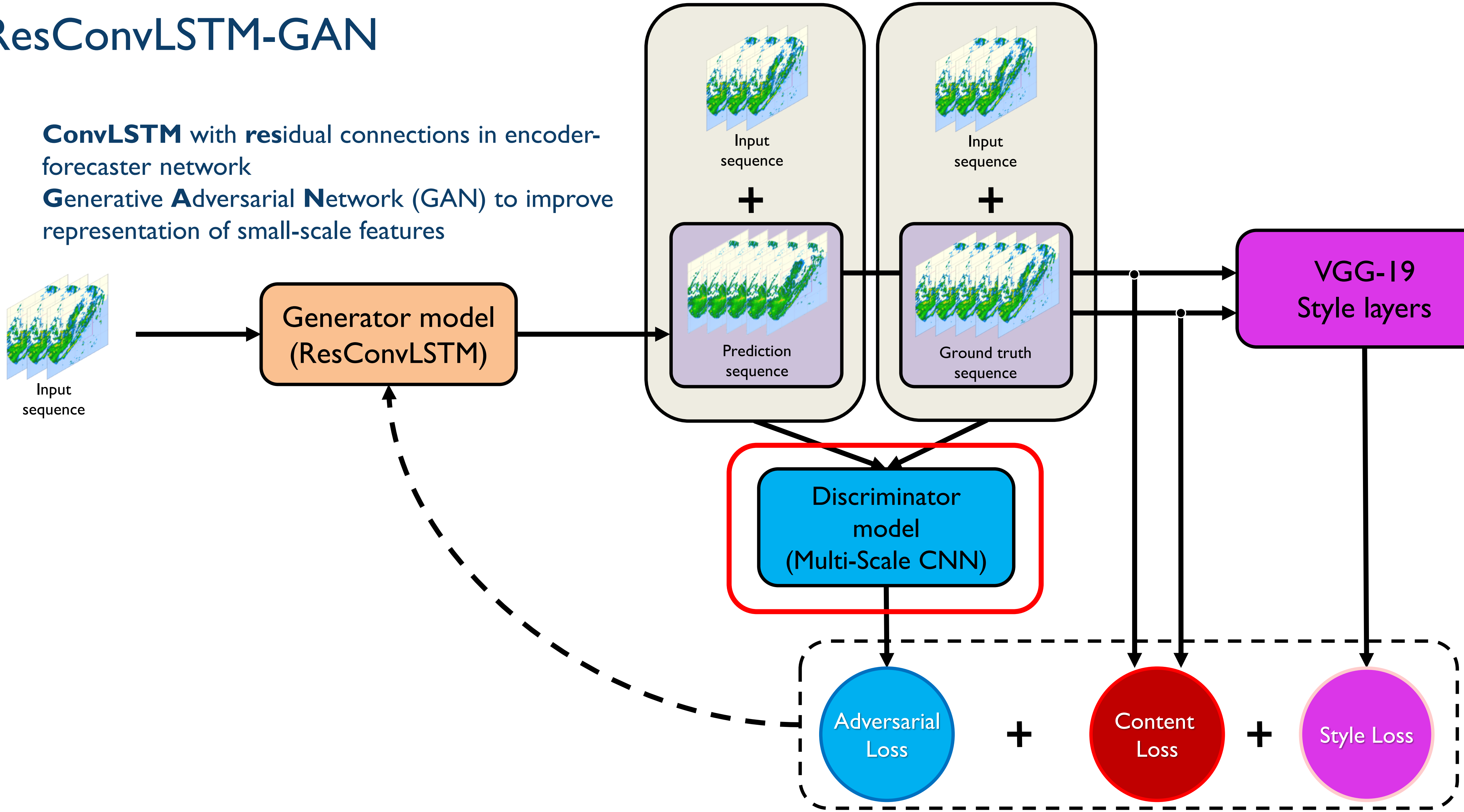
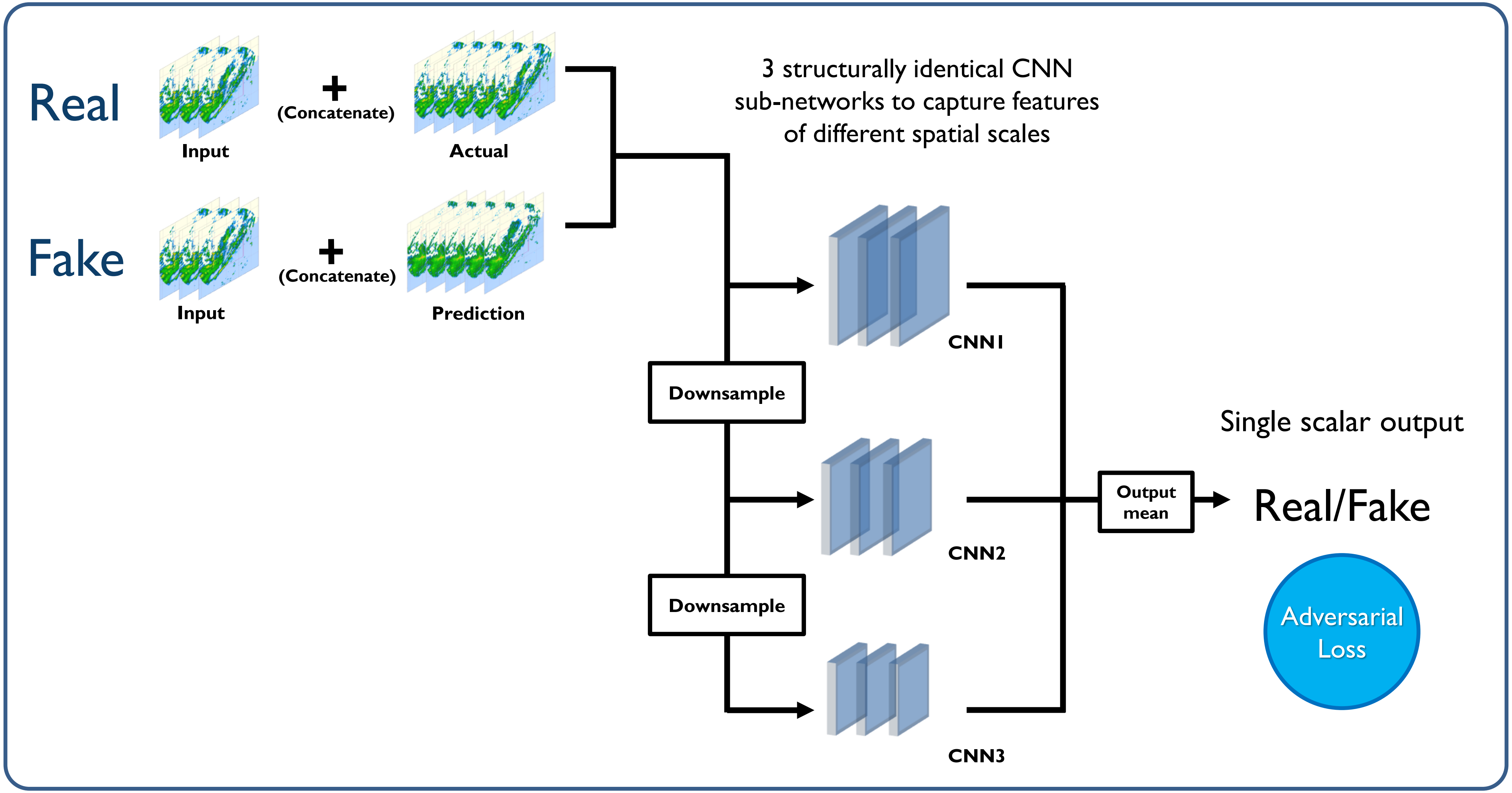


Discriminator: Multi-layer Convolutional Neural Network (CNN)



ResConvLSTM-GAN

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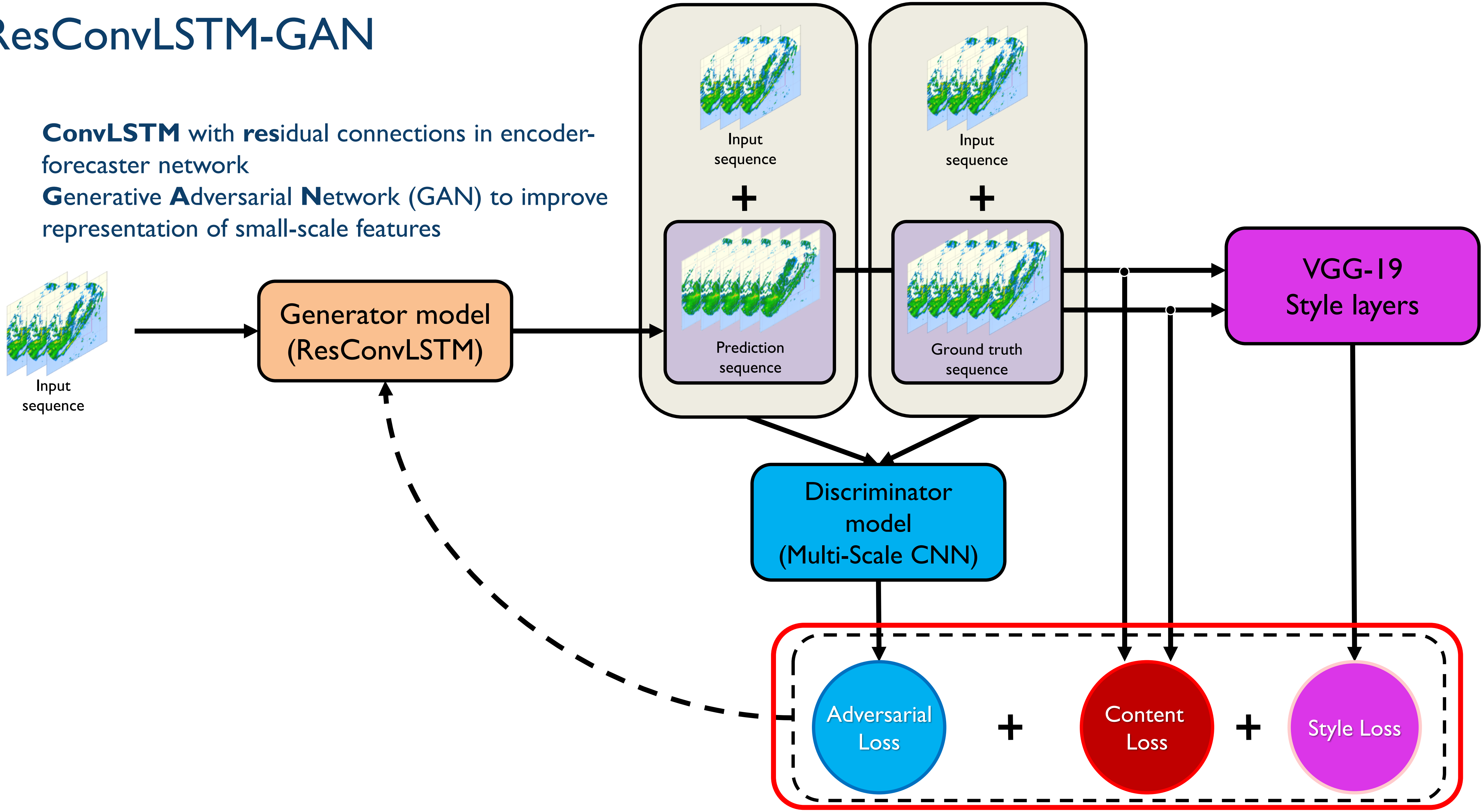
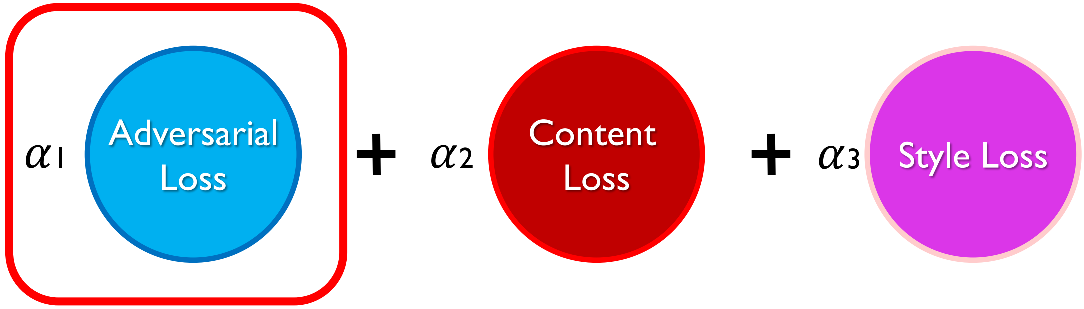


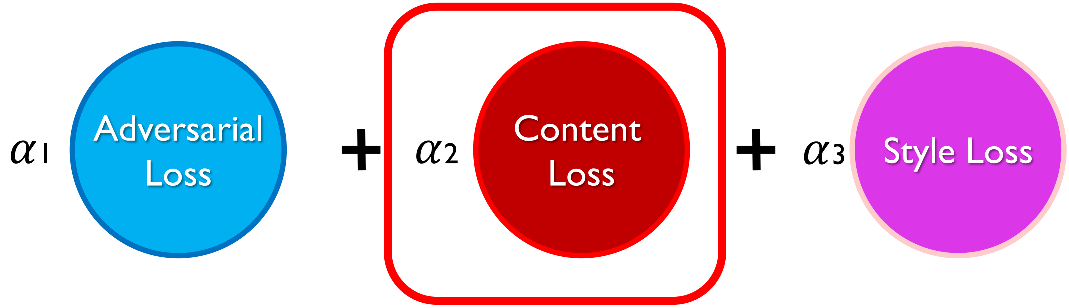
3 Loss Components



Adversarial Loss – Discriminator Loss

- Binary Cross-entropy (BCE) Loss : Predicted Label vs Actual Label
- Aim : To generate realistic radar sequence

3 Loss Components



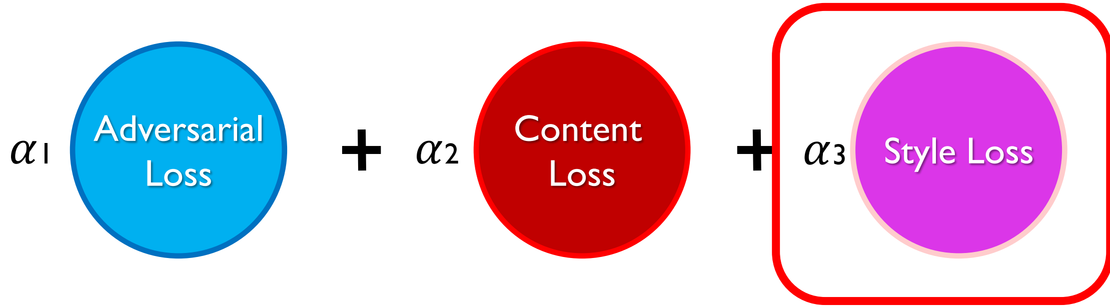
Adversarial Loss – Discriminator Loss

- Binary Cross-entropy (BCE) Loss : Predicted Label vs Actual Label
- Aim : To generate output similar to the actual radar sequence

Content Loss – Part of Generator Loss

- Balanced-MAE-MSE Loss : 50% MAE and 50% MSE with Sample Balancing
- Aim : To generate accurate radar nowcast

3 Loss Components



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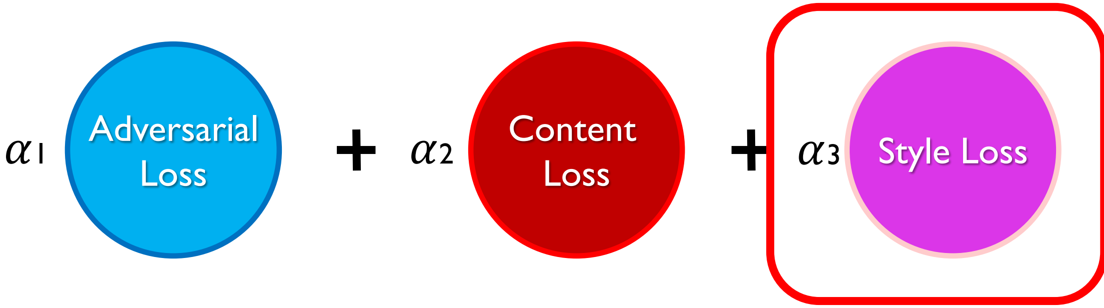
Style Loss – Part of Generator Loss

- Neural Network-based Loss
- Aim : To mimic style of spatial features from input radar sequence

3 Loss Components



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Example from: https://www.tensorflow.org/tutorials/generative/style_transfer

3 Loss Components

α_1 Adversarial Loss + α_2 Content Loss + α_3 Style Loss

Adversarial Loss – Discriminator Loss

- Binary Cross-entropy (BCE) Loss : Predicted Label vs Actual Label
- Aim : To generate output similar to the actual radar sequence

As the loss components are in different scale, α_{1-3} are dynamically balanced and determined during the training process, and will be fixed once they have converged.

Content Loss – Part of Generator Loss

- Balanced-MAE-MSE Loss : 50% MAE and 50% MSE with Sample Balancing
- Aim : To generate accurate radar nowcast

Style Loss – Part of Generator Loss

- Neural Network-based Loss
- Aim : To mimic style of spatial features from input radar sequence

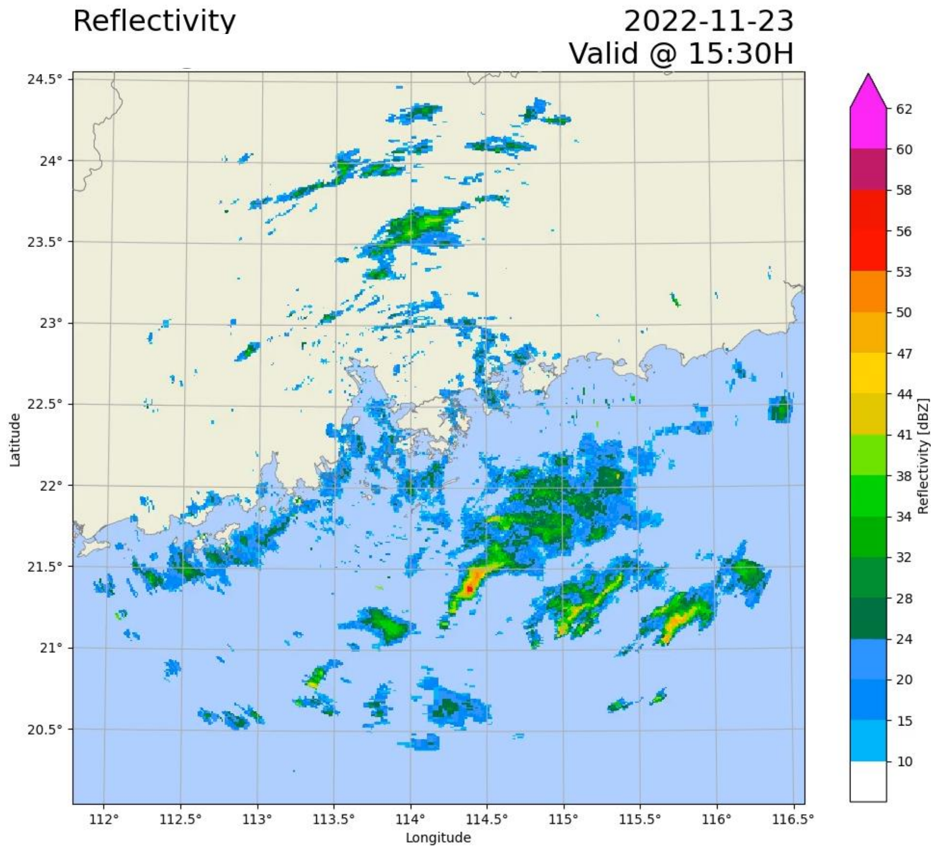
Training Dataset

HKO 2km CAPPI Radar Reflectivity Data

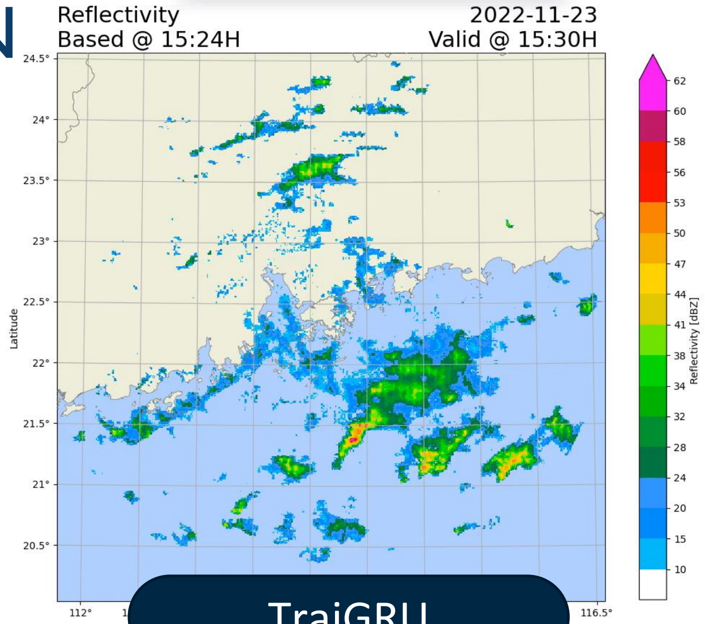
Date range	Train / Valid set: 2009-01 to 2021-05 92000 train sequence 2730 valid sequence	Evaluation set: 2021-06 to 2021-10 5130 test sequence
Domain coverage	256km radius in 480x480 grid	
Input data	5 radar imageries in 6 minutes interval (past 30 minutes)	
Output data	20 radar imageries in 6 minutes interval (2-hour local precipitation nowcast)	

Application of ResConvLSTM-GAN

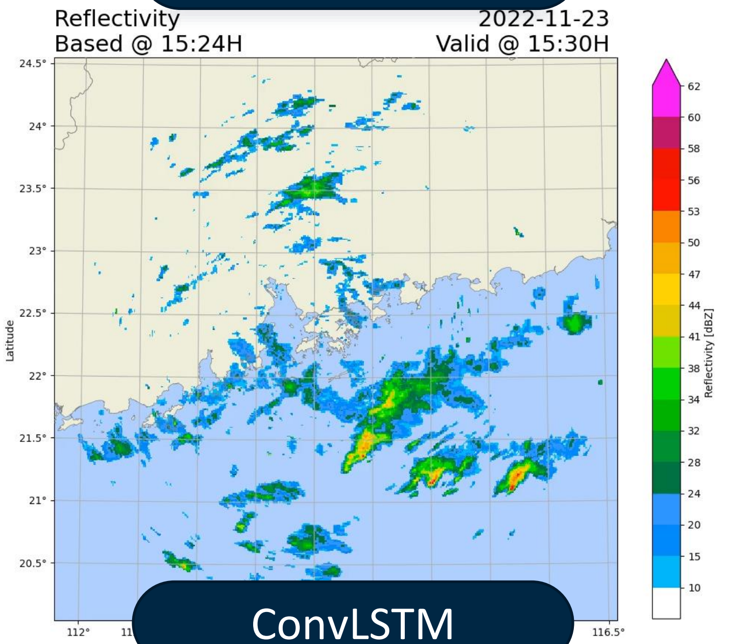
Actual Observations



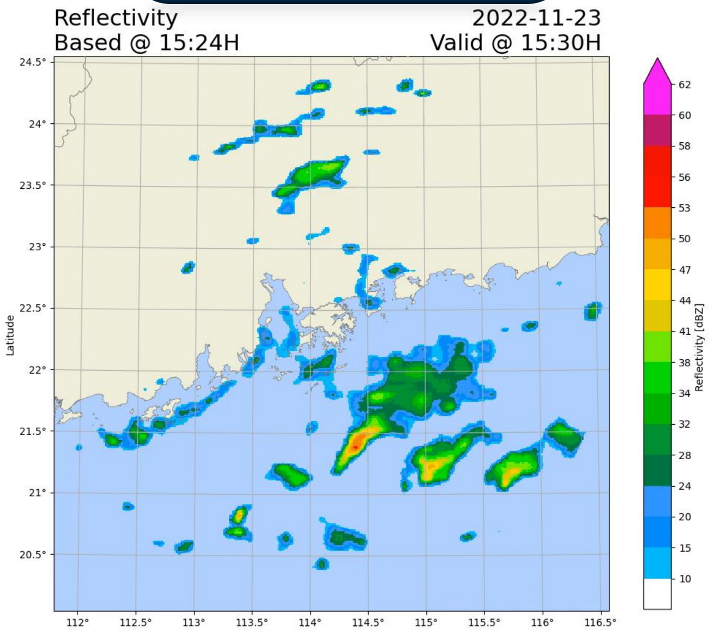
ResConvLSTM-GAN



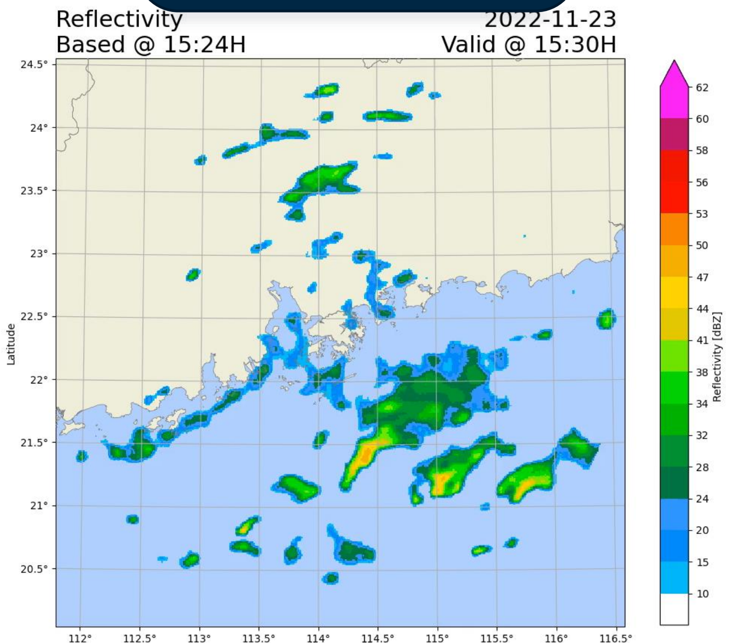
Optical Flow



TrajGRU

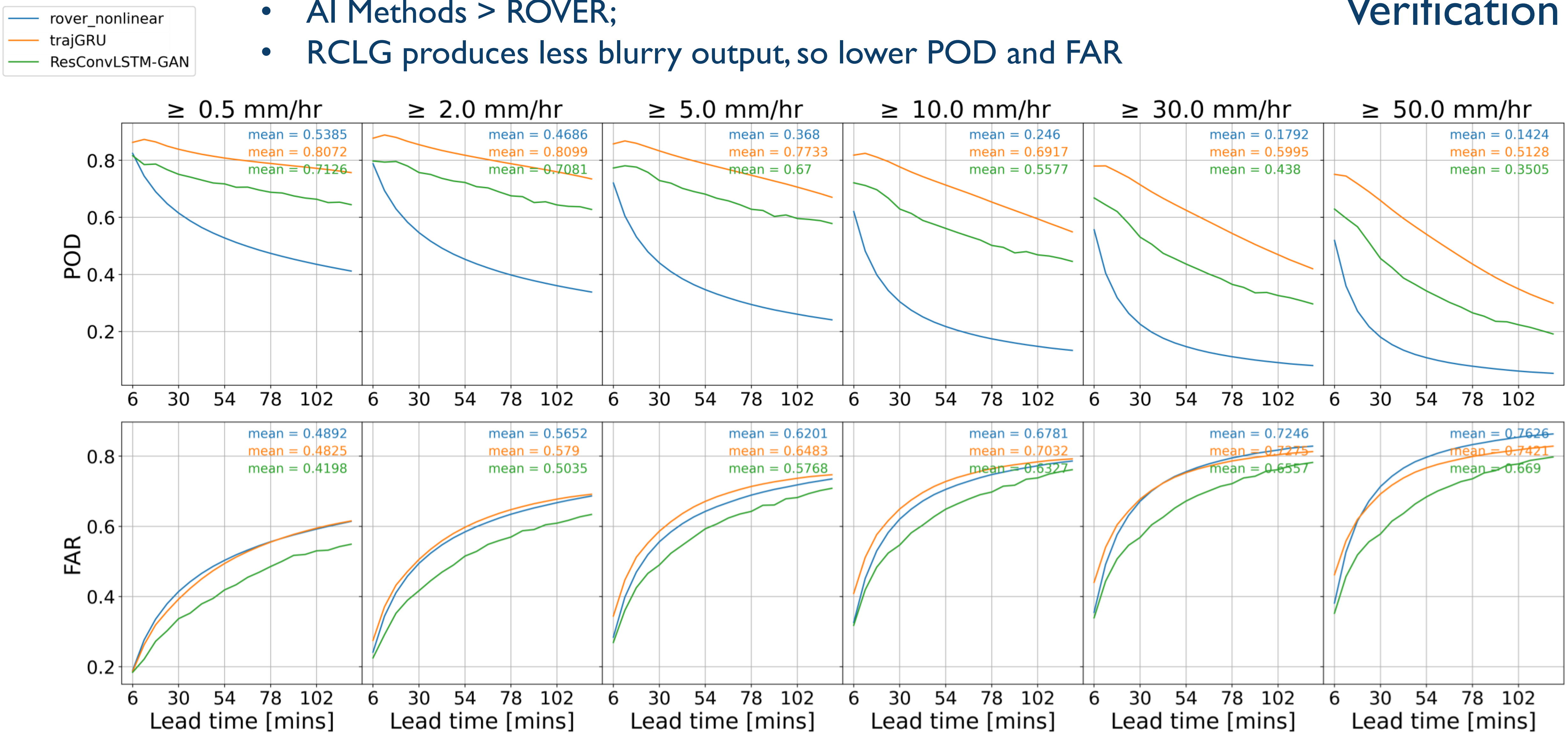


ConvLSTM



Verification

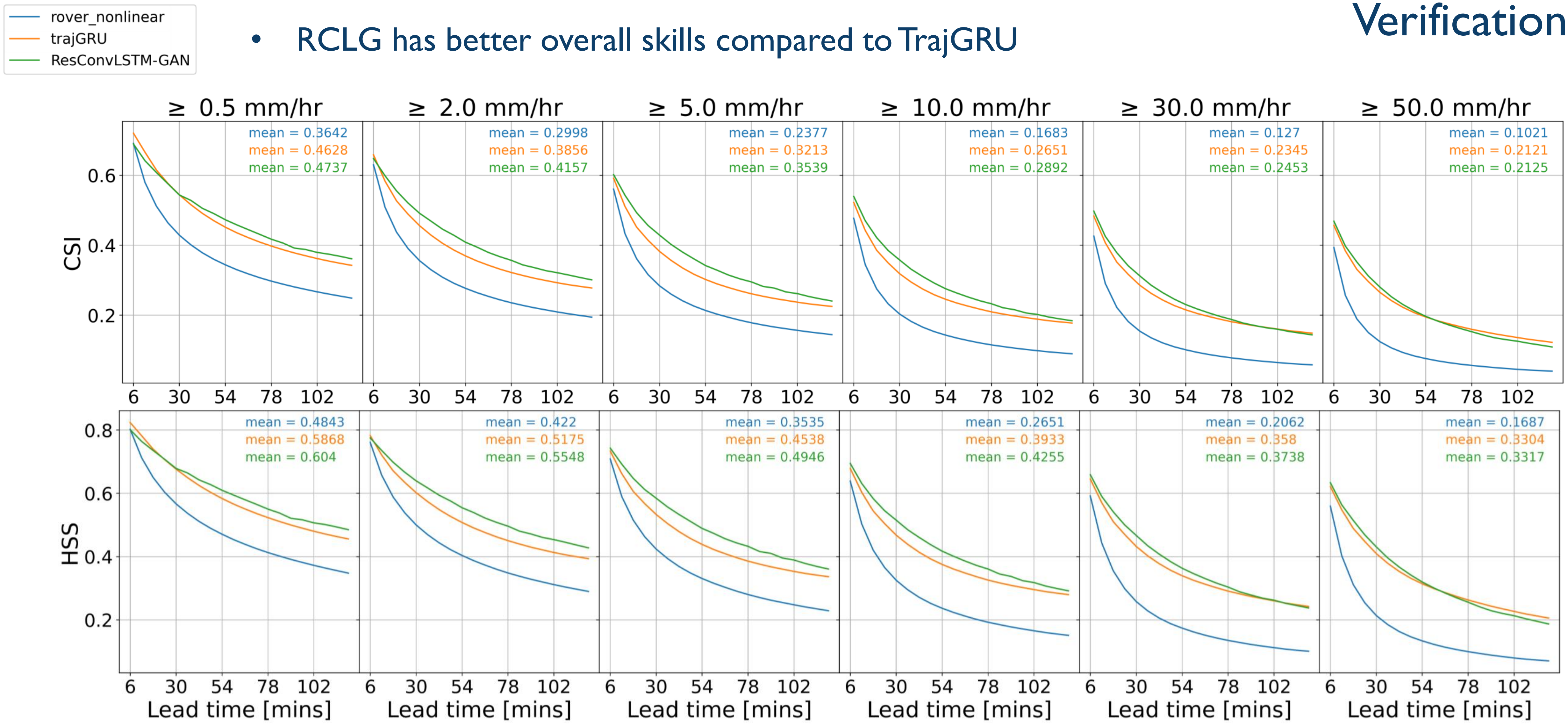
- AI Methods > ROVER;
- RCLG produces less blurry output, so lower POD and FAR



Note: POD – Probability Of Detection ; FAR – False Alarm Rate

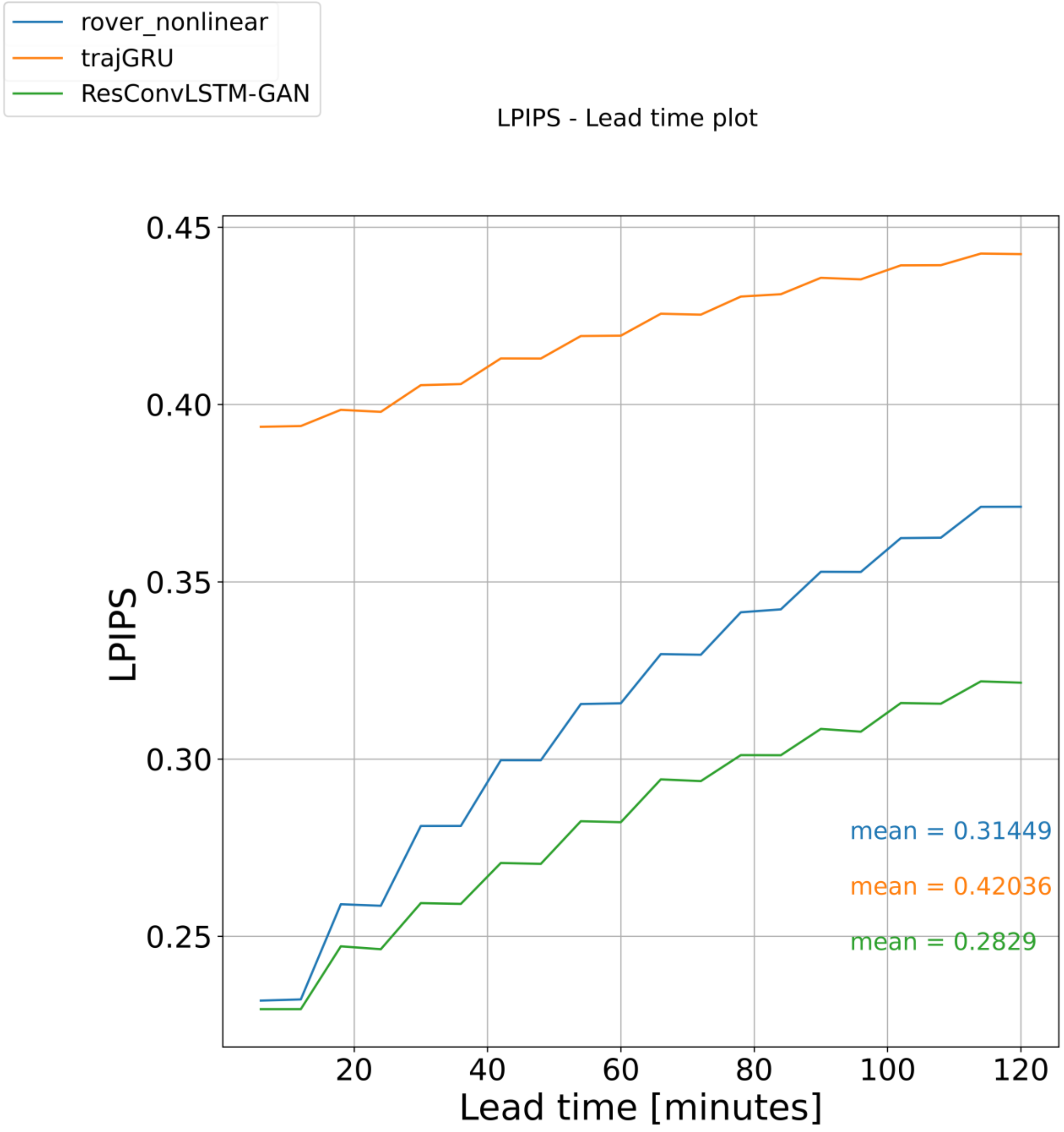
Verification

- RCLG has better overall skills compared to TrajGRU



Note: CSI – Critical Success Index ; HSS - Heidke Skill Score

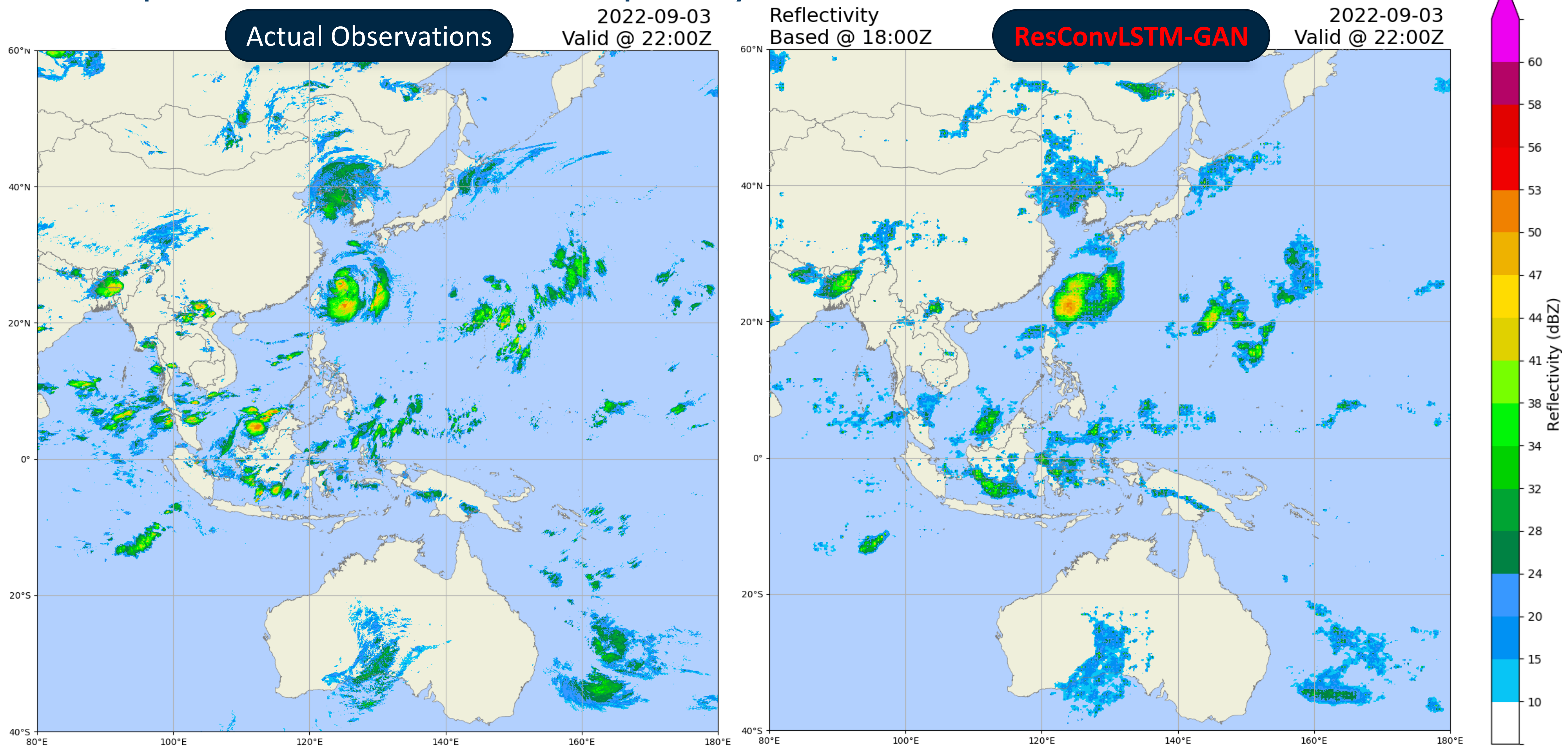
Verification



- 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
- TrajGRU-generated outputs are perceptually dissimilar while RCLG could generate more realistic outputs

	HKO 2km CAPPI Radar Reflectivity Data		H8-GK2A Satellite Simulated Reflectivity Data	
Date range	Train / Valid set: 2009-01 to 2021-05 92000 train sequence 2730 valid sequence	Evaluation set: 2021-06 to 2021-10 5130 test sequence	Train / Validation set: 2021-02 to 2022-09 66320 train sequence 11180 valid sequence	Evaluation set: 2022-10 to 2023-02 13580 test sequence
Domain coverage	256km radius in 480x480 grid		2501x2501 grid from (lat 60°N, lon 80°E) to (lat 40°S, lon 180°E)	
Input data	5 radar maps of 6 minutes interval (past 30 minutes)		6 satellite maps of 20 minutes interval (past 2 hour)	
Output data	20 radar maps of 6 minutes interval (2-hour local precipitation nowcast)		12 satellite maps of 20 minutes interval (4 hours regional satellite reflectivity nowcast)	

A Sample of Satellite Nowcast – Tropical Cyclone Hinnamnor



Concluding Remarks and Future Work

- ResConvLSTM-GAN is capable of generating more accurate and realistic radar nowcasts over the next 2 hours and the framework is applicable to satellite nowcast
- To replace the generator and discriminator by more efficient deep learning modules
  - e.g. Transformer-based model, Wasserstein GAN
- To implement a physics-driven nowcast framework

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Thank you very much