Deep Learning Nowcast

WOO Wang-chun
Hong Kong Observatory
Research Forum
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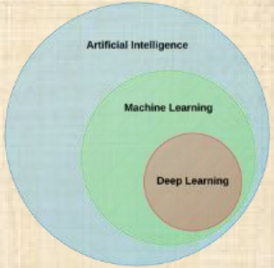
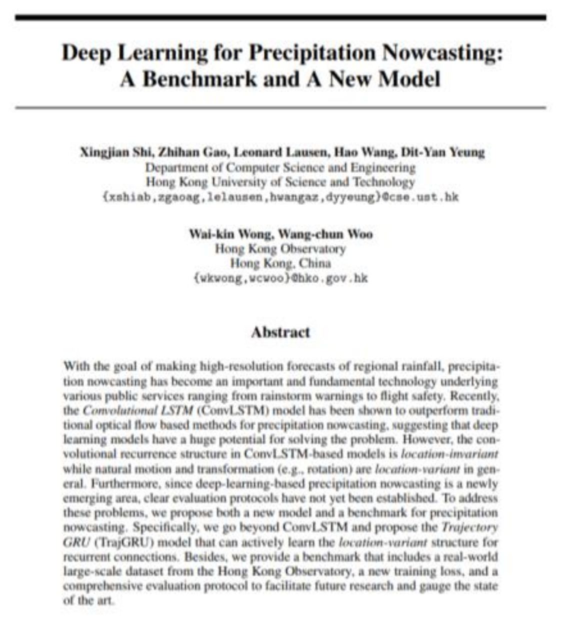


A Brief History

Year	Event
2014	Initiated collaboration with HKUST
2015	ConvLSTM developed, outperforming ROVER for rain/no-rain (0.5 mm/h), resolution limited to 100x100 only
2016	Model enhancement and adaptation
2017	TrajGRU developed and benchmarked, outperforming ROVER for 30mm/h support arbitrary resolution

Paper on NIPS2017



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

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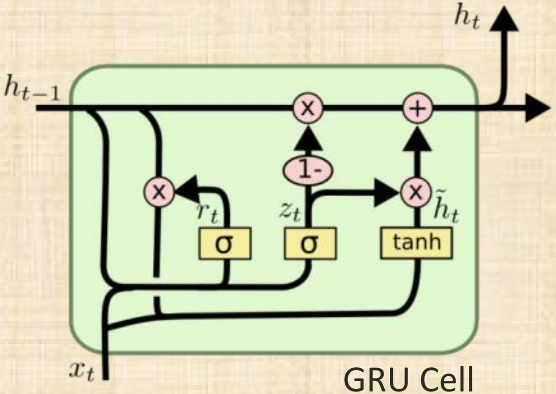
Abstract

With the goal of making high-resolution forecasts of regional rainfall, precipitation nowcasting has become an important and fundamental technology underlying various public services ranging from rainstorm warnings to flight safety. Recently, the *Convolutional LSTM* (ConvLSTM) model has been shown to outperform traditional optical flow based methods for precipitation nowcasting, suggesting that deep learning models have a huge potential for solving the problem. However, the convolutional recurrence structure in ConvLSTM-based models is *location-invariant* while natural motion and transformation (e.g., rotation) are *location-variant* in general. Furthermore, since deep-learning-based precipitation nowcasting is a newly emerging area, clear evaluation protocols have not yet been established. To address these problems, we propose both a new model and a benchmark for precipitation nowcasting. Specifically, we go beyond ConvLSTM and propose the *Trajectory GRU* (TrajGRU) model that can actively learn the *location-variant* structure for recurrent connections. Besides, we provide a benchmark that includes a real-world large-scale dataset from the Hong Kong Observatory, a new training loss, and a comprehensive evaluation protocol to facilitate future research and gauge the state of the art.

https://papers.nips.cc/paper/7145-deep-learning-for-precipitation-nowcasting-a-benchmark-and-a-new-model.pdf

Deep Learning Nowcast developed

Based on Trajectory Gated Recurrent Unit (TrajGRU):



GRU Cell

$$\mathcal{U}_t, \mathcal{V}_t = \gamma(\mathcal{X}_t, \mathcal{H}_{t-1}),$$

$$\mathcal{Z}_t = \sigma(\mathcal{W}_{xz} * \mathcal{X}_t + \sum_{l=1}^{L} \mathcal{W}_{hz}^{l} * \text{warp}(\mathcal{H}_{t-1}, \mathcal{U}_{t,l}, \mathcal{V}_{t,l})),$$

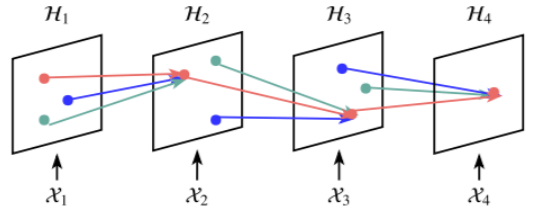
$$\mathcal{R}_t = \sigma(\mathcal{W}_{xr} * \mathcal{X}_t + \sum_{l=1}^{L} \mathcal{W}_{hr}^{l} * \text{warp}(\mathcal{H}_{t-1}, \mathcal{U}_{t,l}, \mathcal{V}_{t,l})),$$

$$\mathcal{H}_t' = f(\mathcal{W}_{xh} * \mathcal{X}_t + \mathcal{R}_t \circ (\sum_{l=1}^{L} \mathcal{W}_{hh}^{l} * \text{warp}(\mathcal{H}_{t-1}, \mathcal{U}_{t,l}, \mathcal{V}_{t,l}))),$$

$$\mathcal{H}_t = (1 - \mathcal{Z}_t) \circ \mathcal{H}_t' + \mathcal{Z}_t \circ \mathcal{H}_{t-1}.$$

Innovations:

1) Trajectory



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

2) Weighted Error Function

$w(x)$ 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.

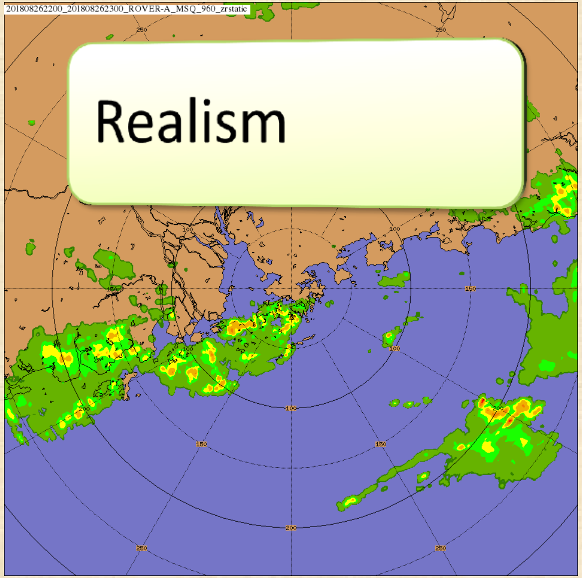
Performance of TrajGRU

Algorithms	HSS ↑ $r \geq 0.5$	$r \geq 2$	$r \geq 5$	$r \geq 10$	$r \geq 30$	B-MSE ↓	B-MAE ↓
	Offline Setting						
Last Frame	0.5207	0.4531	0.3582	0.2512	0.1193	15274	28042
ROVER + Linear	0.6038	0.5473	0.4516	0.3301	0.1762	11651	23437
ROVER + Non-linear	0.5896	0.5436	0.4590	0.3318	0.1576	10945	22857
2D CNN	0.6366	0.5809	0.4851	0.3690	0.1885	7332	18091
3D CNN	0.6334	0.5825	0.4862	0.3734	0.2034	7202	17593
ConvGRU-nobal	0.6756	0.6094	0.4981	0.3286	0.1160	9087	19642
ConvGRU	0.6701	0.6104	0.5163	0.4159	0.2893	5951	15000
TrajGRU	**0.6731**	**0.6126**	**0.5192**	**0.4207**	**0.2996**	**5816**	**14675**
	Online Setting						
2D CNN	0.6365	0.5756	0.4790	0.3744	0.2162	6654	17071
3D CNN	0.6355	0.5736	0.4766	0.3733	0.2220	6690	16903
ConvGRU	0.6712	0.6105	0.5183	0.4226	0.2981	5724	14772
TrajGRU	**0.6760**	**0.6164**	**0.5253**	**0.4308**	**0.3111**	**5589**	**14465**

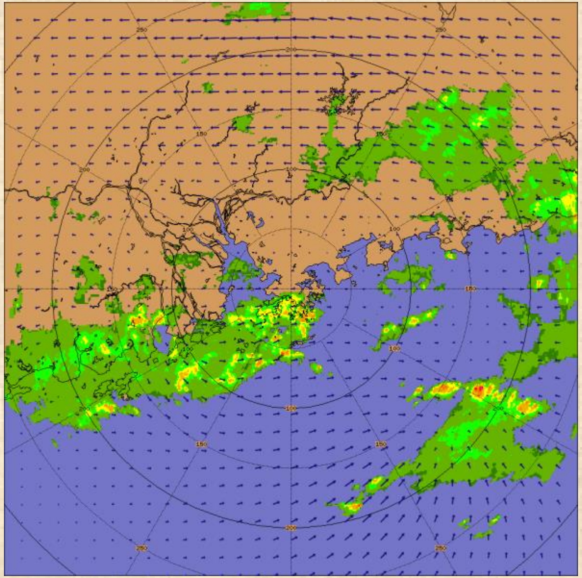
Red 紅

23:05

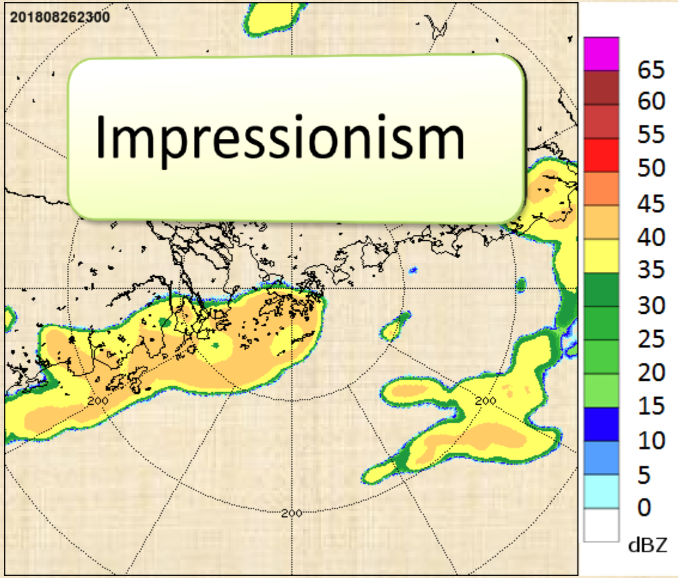
60-min Forecast Reflectivity Based at 2018/08/26 23:00H



Optical Flow (ROVER)



Actual

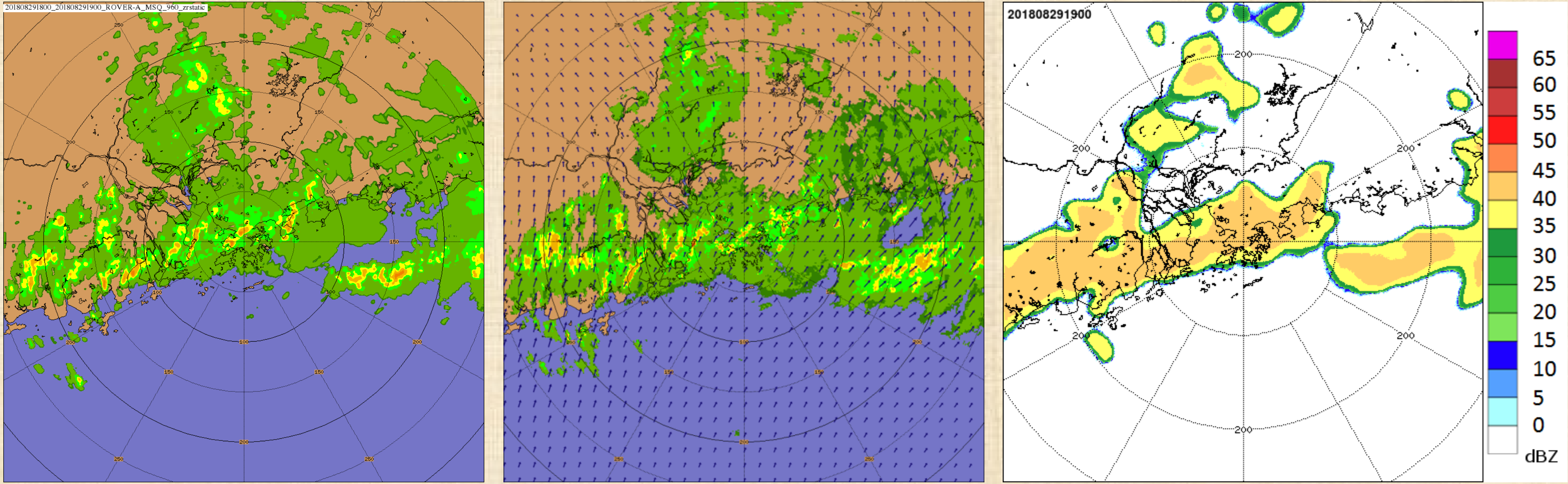


Deep Learn (TrajGRU)

60-min Forecast Reflectivity Based at 2018/08/29 18:00

Red 紅

18:40

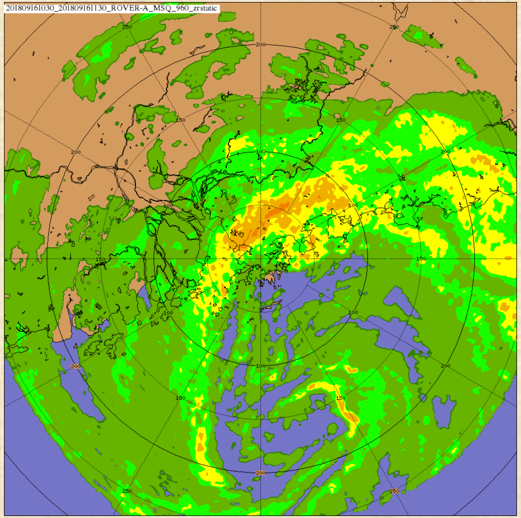


Optical Flow (ROVER) **Actual** Deep Learn (TrajGRU)

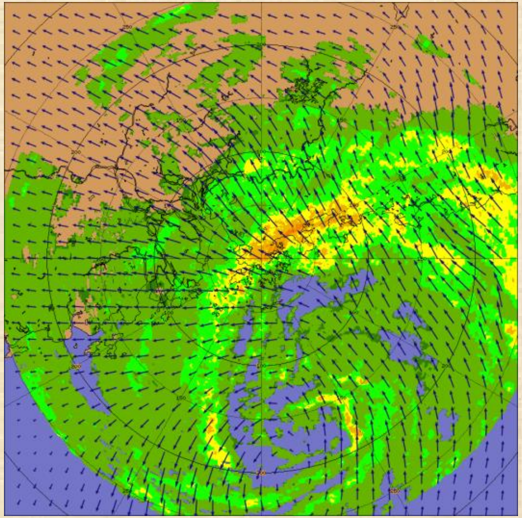
Amber 黃

09:10

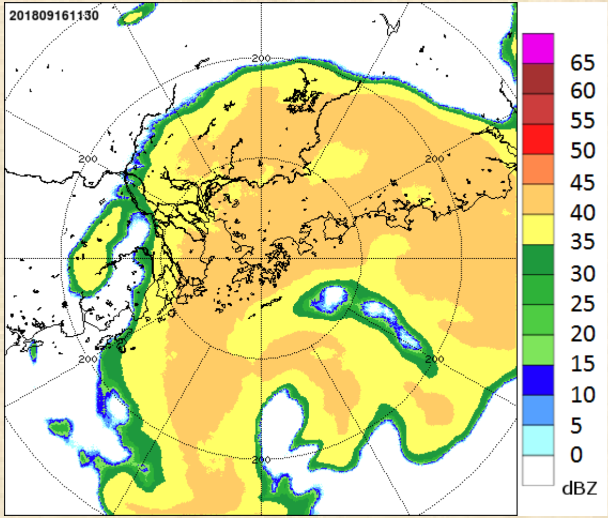
60-min Forecast Reflectivity Based at 2018/09/16 10:30



Optical Flow (ROVER)

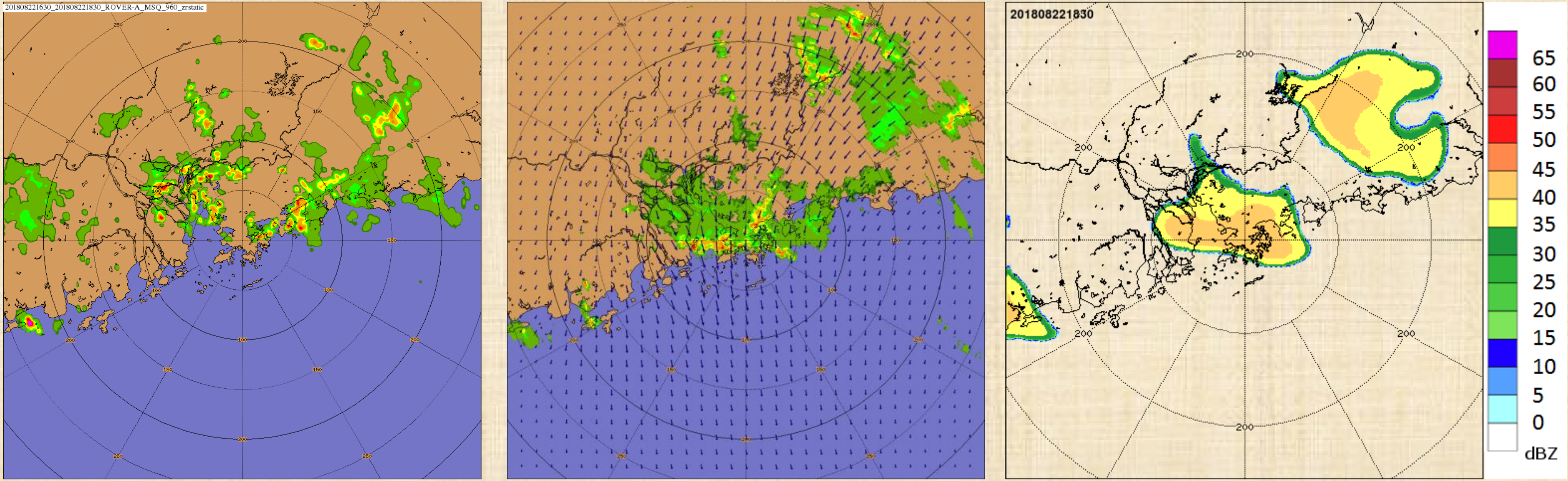


Actual



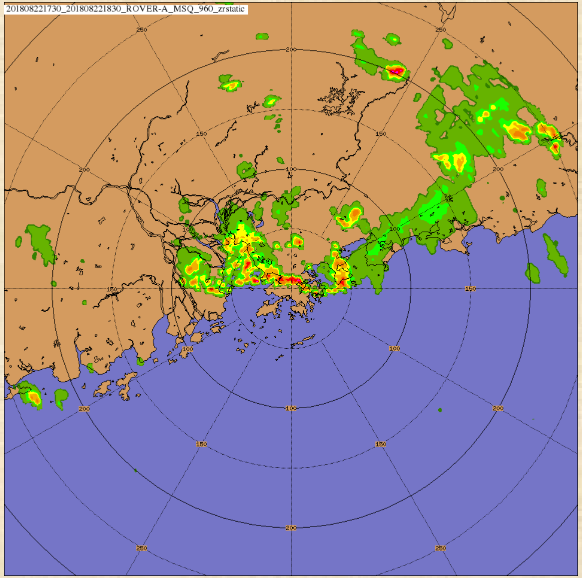
Deep Learn (TrajGRU)

120-min Forecast Reflectivity Based at 2018/08/22 16:30

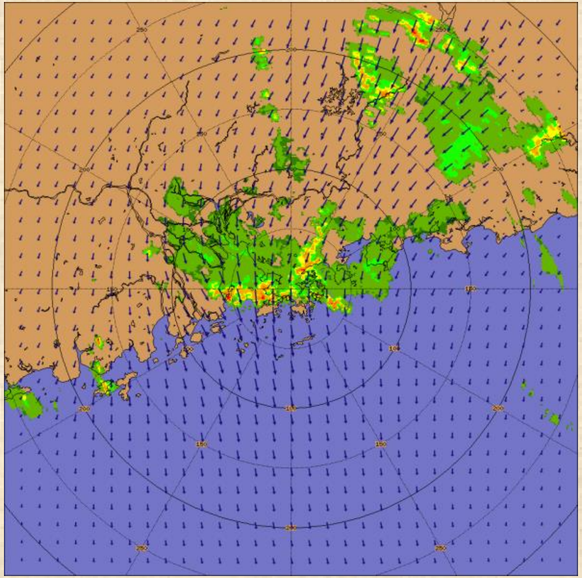


Optical Flow (ROVER) **Actual** Deep Learn (TrajGRU)

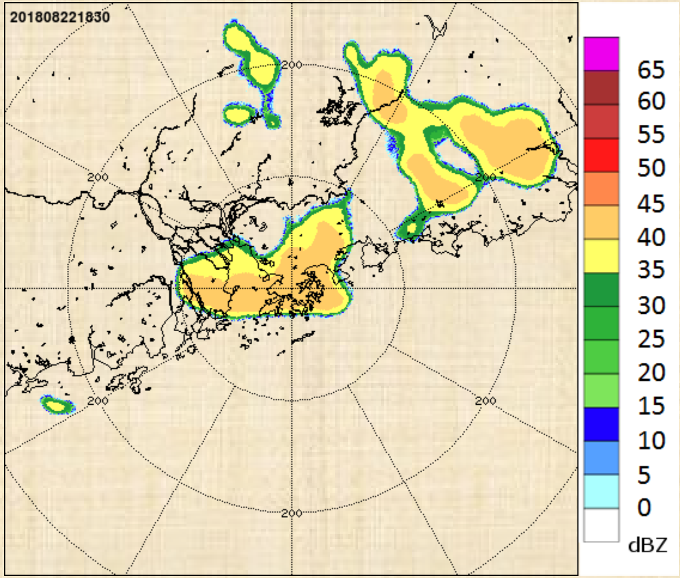
60-min Forecast Reflectivity Based at 2018/08/22 17:30



Optical Flow (ROVER)

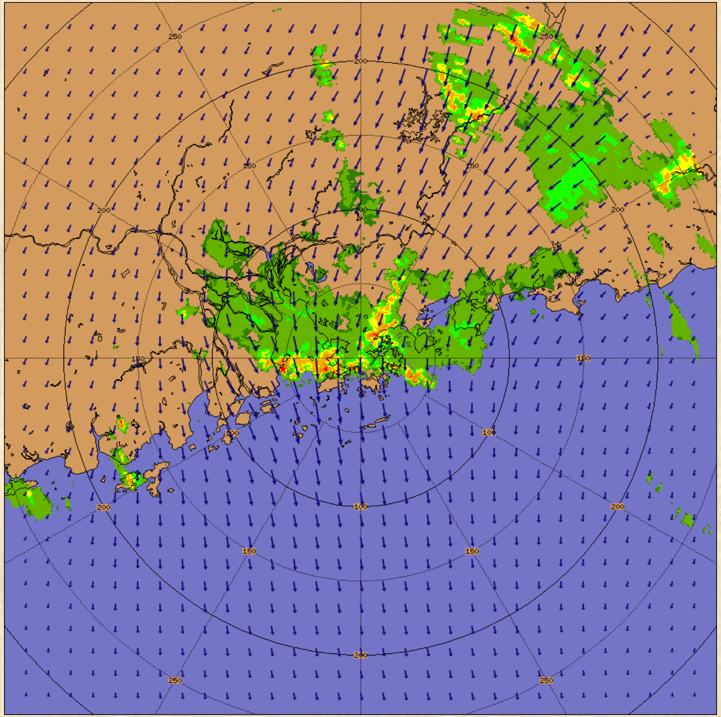


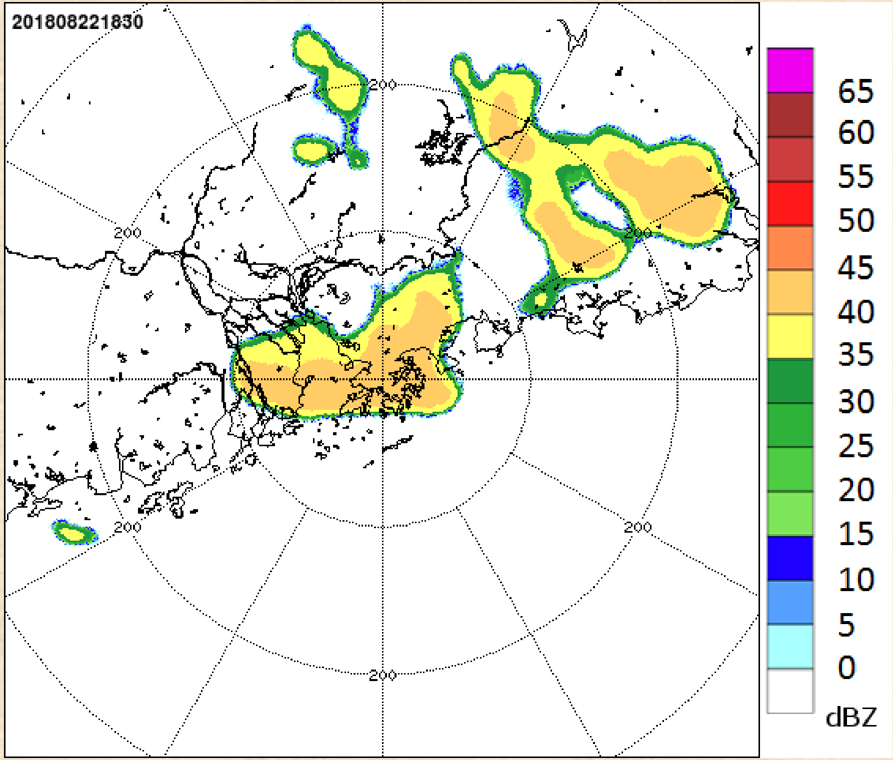
Actual



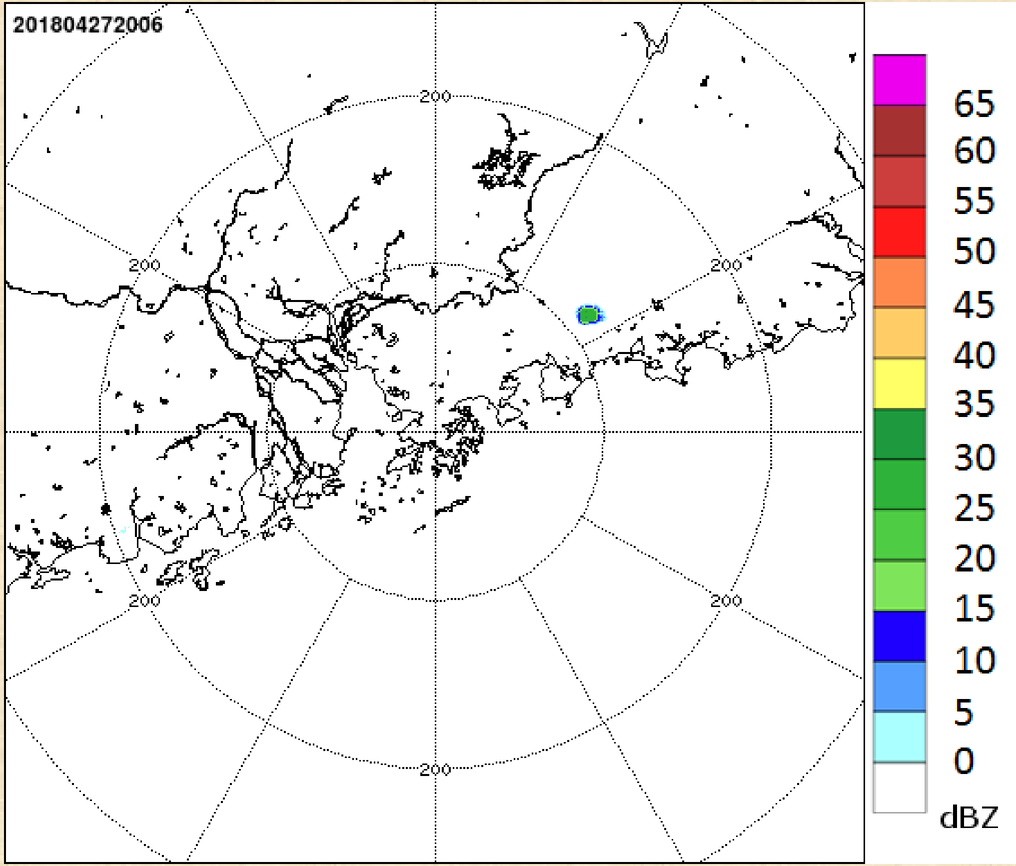
Deep Learn (TrajGRU)

Deep Learn (TrajGRU) 2018/08/22 Various Base Time; Valid at 18:30H





Decay?



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55
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15
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dBZ

Discussion on “Decay”

sxjscience commented on 3 Apr — Owner

是H_t，forecaster的第一个RNN的data是全0

chencodeX commented on 10 Apr

您在训练的时候有没有发现，预测的结果中，越往后的时刻，整体图像的亮度在不断变暗。

sxjscience commented on 11 Apr — Owner

有观察到过这个现象

Get Outlook for iOS<https://aka.ms/o0ukef>

chencodeX commented on 11 Apr

您是怎么解决这个问题的呢?

chencodeX commented on 12 Apr

在您的论文中，有一部分是关于dBZ和降雨等级之间的转换的。

> As rainfall events occur sparsely, we select the rainy days based on the rain barrel information to form our final dataset, which has 812 days for training, 50 days for validation and 131 days for testing. Our current treatment is close to the real-life scenario as we are able to train an additional model that classifies whether or not it will rain on the next day and applies our precipitation nowcasting model if this coarser-level model predicts that it will be rainy. The radar reflectivity values are converted to rainfall intensity values (mm/h) using the Z-R relationship: $\text{dBZ} = 10\log a + 10b\log R$ where R is the rain-rate level, $a = 58.53$ and $b = 1.56$. The overall statistics and the average monthly rainfall distribution of the HKO-7 dataset are given in the appendix.

请问您这个log是以十为底还是以自然对数为底呢？

sxjscience commented on 12 Apr — Owner

10为底

Get Outlook for iOS<https://aka.ms/o0ukef>

chencodeX commented on 12 Apr

以10为底的时候，dBZ为70的情况下，R为2260. 这正常吗?

chencodeX closed this on 12 Apr

wcwoo commented on 28 Apr — Collaborator

雷達dBZ正常不超過65，其實在60很可能已在落冰雹了。
關於採用的a,b值，是根據三年實測數據以TMM和綫性回歸計算出來的。

wcwoo reopened this on 28 Apr

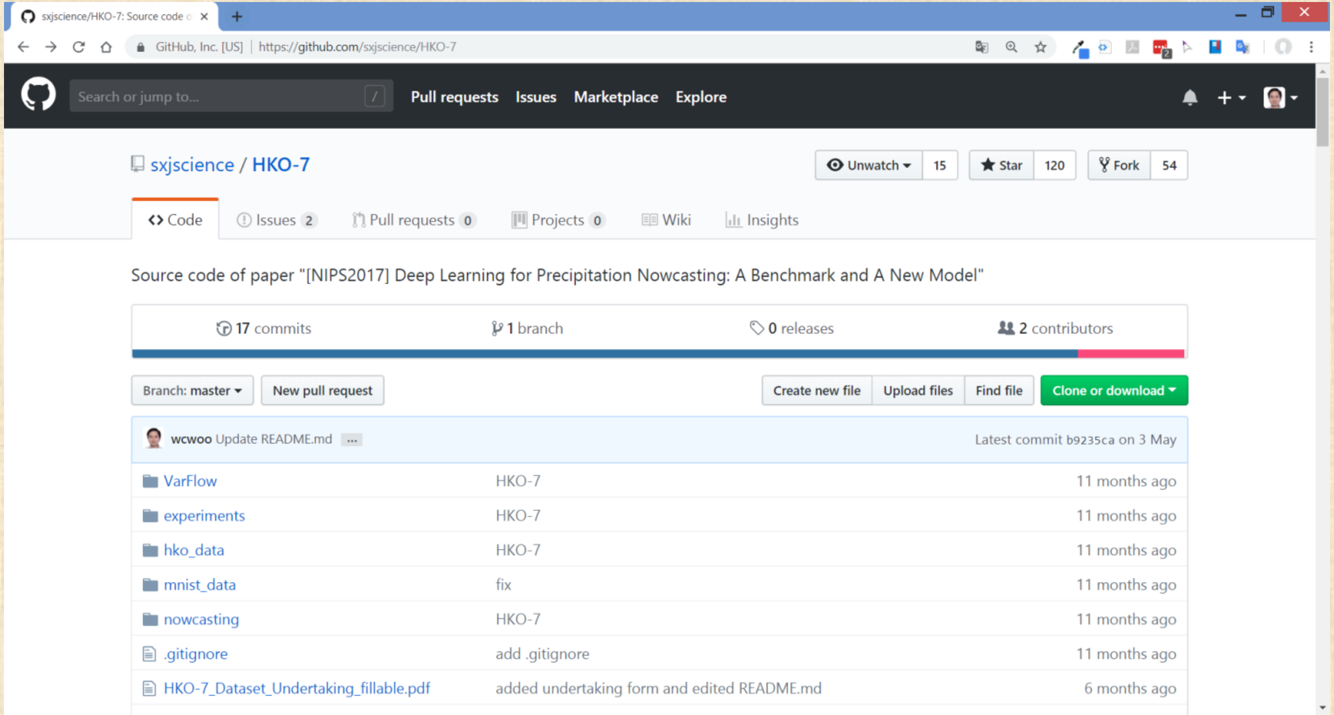
wcwoo commented on 1 May — Collaborator

有關整體圖像不斷變暗的現象，在我們業務測試中也有留意到。我猜想是因為神經網絡明白了外推法的限制，所以當預報時限足夠長時寧願什麼都不預測。這也涉及評分準則，因為是定時定點計算，而且加重了大雨的權重，對長時間預報任何預測都幾乎成為空報，同時又未能減少漏報，所以最優化的策略就是不報了。將來可以考慮改用三維（時空）FSS，或讓評分有點容錯度，以改善這個情況。

chencodeX commented on 2 May

非常感谢您的解答

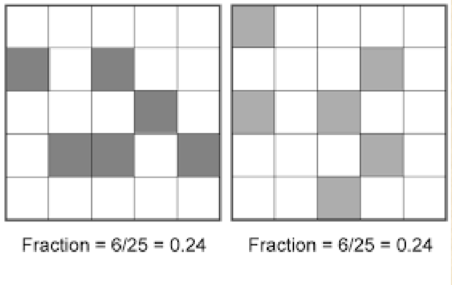
DL/Traj-GRU on Github



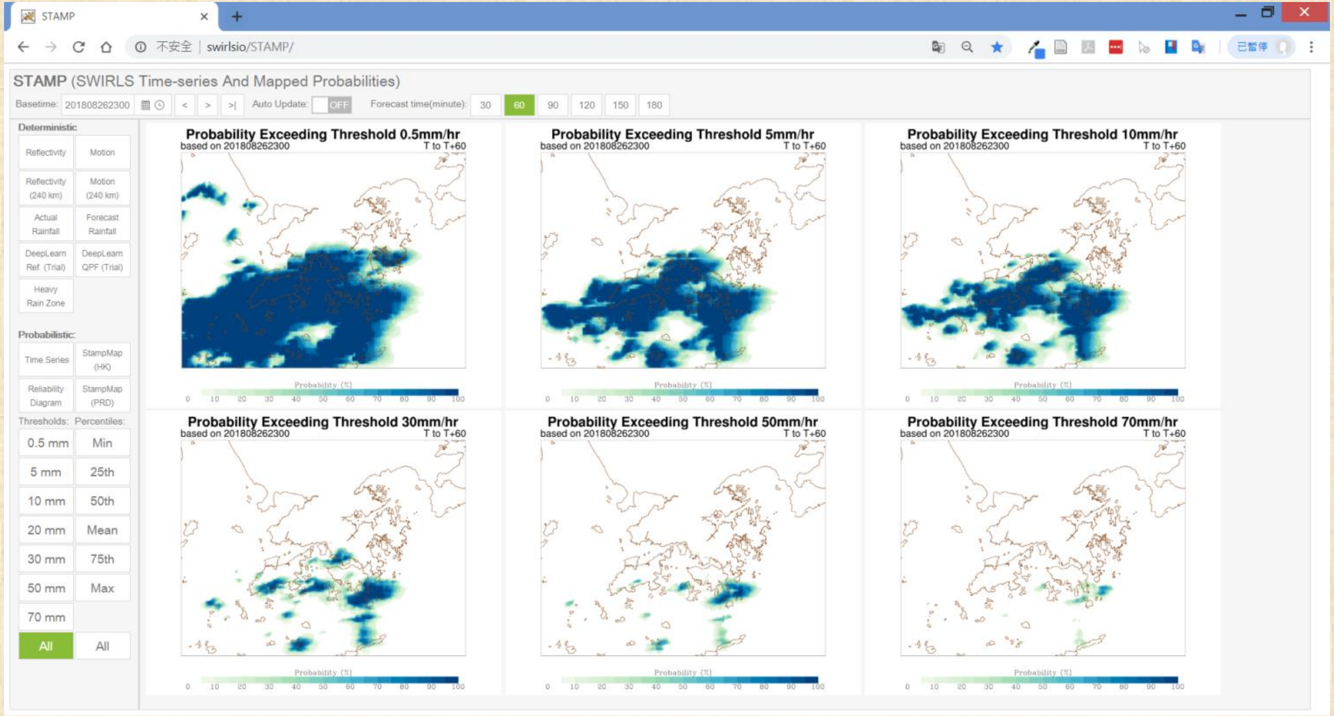
WAY FORWARD

Better Error Function (Deterministic)

- May consider functions with **higher tolerance and thus less double penalty** to achieve *More Realism*, e.g.
  - Spatial-Temporal Smoothing
  - Fractional Skill Score (FSS)

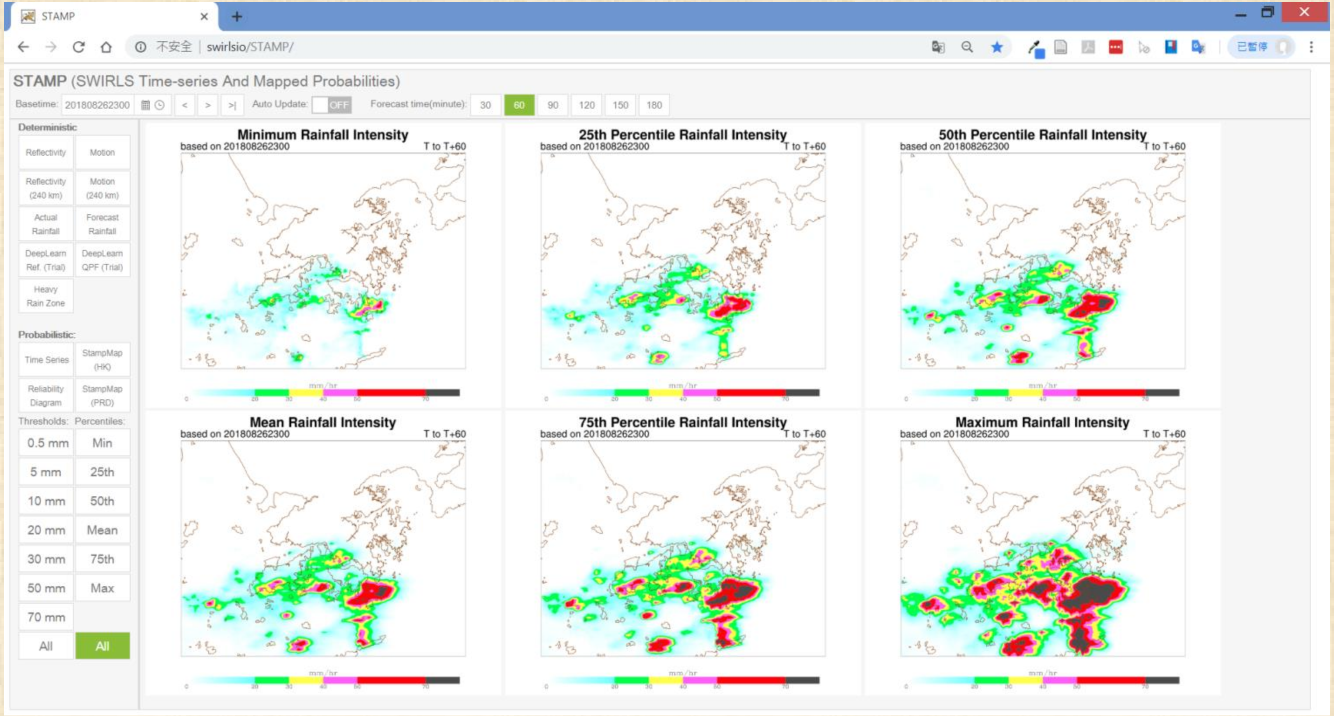


Probabilistic Rainfall Nowcast Based on Optical Flow (ROVER)



Probability at Selected Thresholds

Probabilistic Rainfall Nowcast Based on Optical Flow (ROVER)



Rainfall Intensity at Selected Percentile

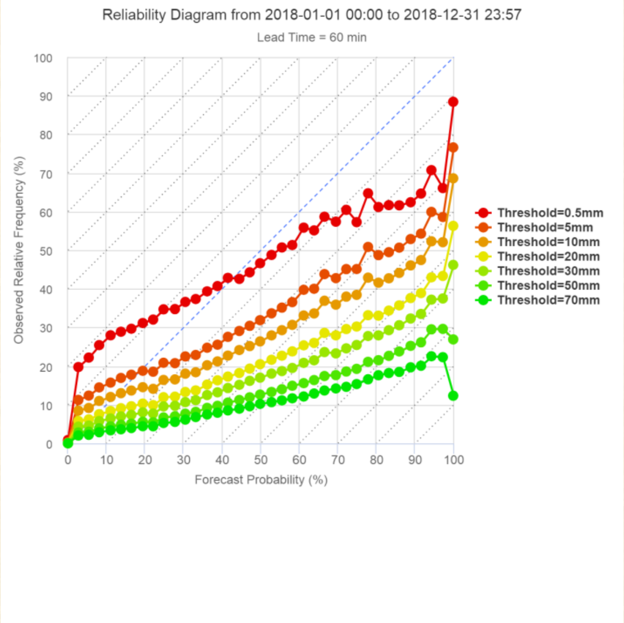
Probabilistic Rainfall Nowcast Based on Deep Learn (TrajGRU)

?

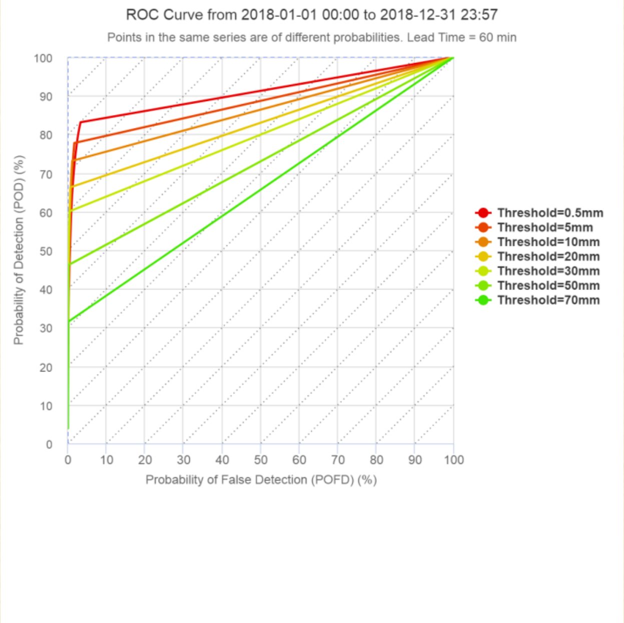
- Possible Way:
  - Time-Lagged Ensemble (TLE)
  - Make an ensemble of 36 members based on 9 years of data, instead of 7, i.e. "${}_9C_7=36$"

Error Function (Probabilistic)

Reliability Diagram



ROC Curve



Other Deep Learning Applications

- State of Sky and Visibility from Web Cam
- Rainfall Rate from Satellite Data
- Probabilities of Rainstorms
- Onset of Sea Breeze for Aviation

Thank You!

THE END