Short-term forecasting of Typhoon rainfall with deep learning-based disaster monitoring model

Climate Informatics 2023

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19, April, 2023

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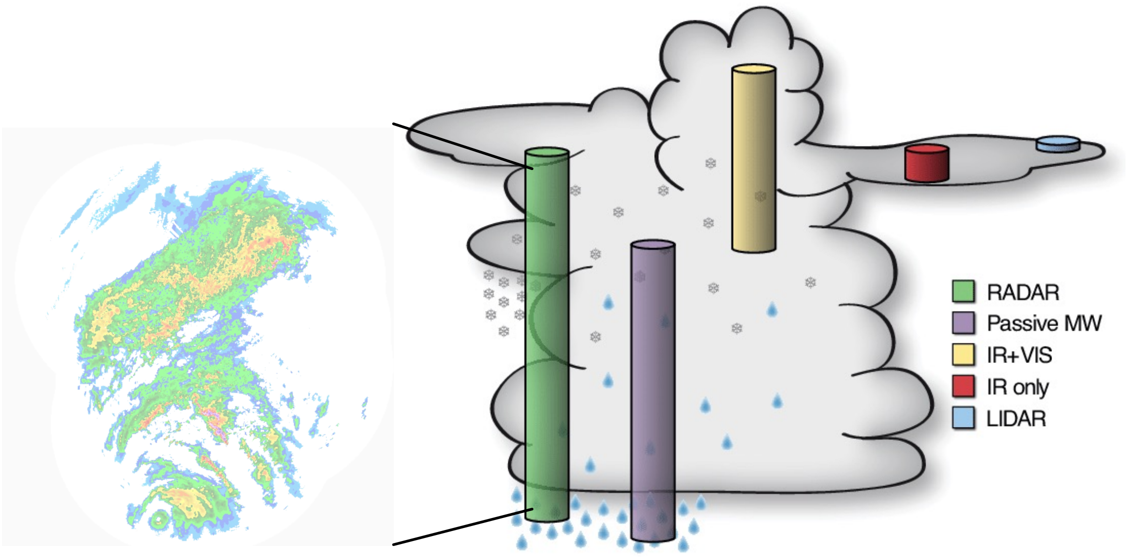
Chapter 01

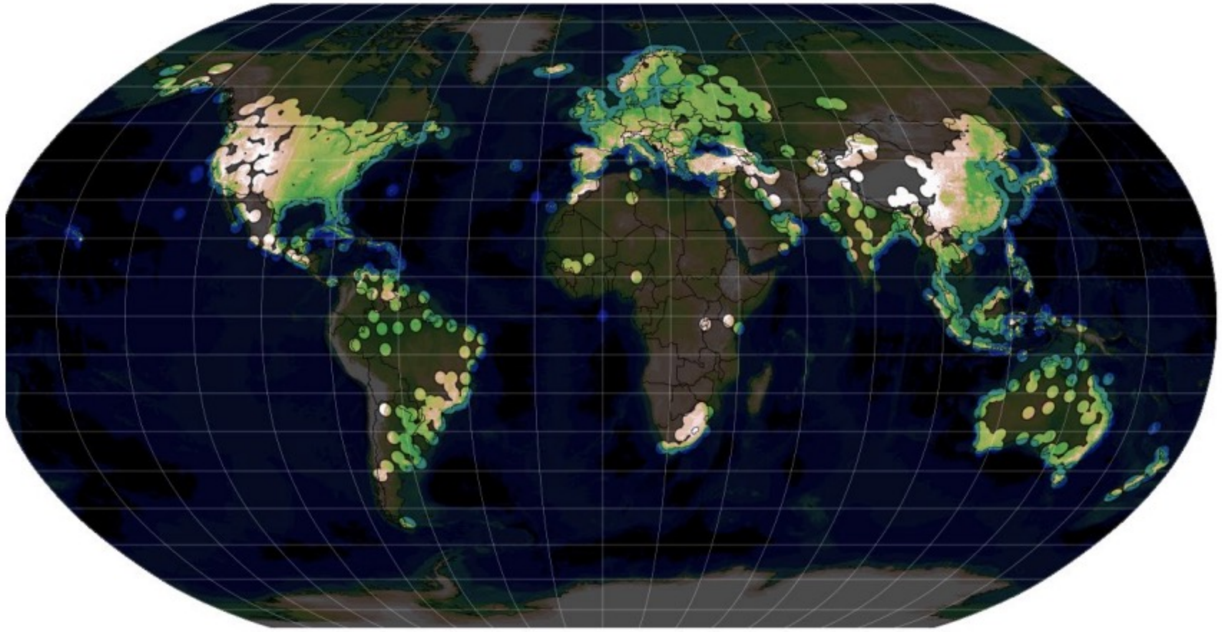
Background

Background

- Weather radar detects and quantifies precipitation and severe weather
- It covers densely populated areas, but still insufficient to cover some regions and oceans



Different measurement techniques in a thick cloud [1]



A map of weather radar coverage [2]

[1] Eliasson, Salomon, et al. "Assessing observed and modelled spatial distributions of ice water path using satellite data." *Atmospheric Chemistry and Physics* 11.1 (2011): 375-391.
[2] Saltikoff, Elena, et al. "An overview of using weather radar for climatological studies: successes, challenges, and potential." *Bulletin of the American Meteorological Society* 100.9 (2019): 1739-1752.

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Goal

Accuracy Weather Forecasting without Radar System

Spatio-temporal limited detection → Future Satellite video prediction

Insufficient Radar system → Proxy radar map from satellite images

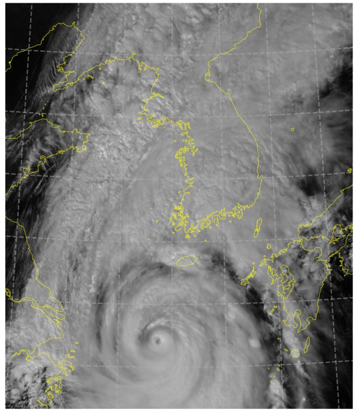
Chapter 02

Data and Method

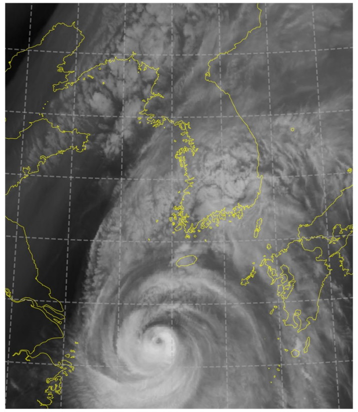
Data

- **Geo-KOMPSAT-2A (GK2A)**
  - Geostationary orbit satellite
  - 2-minutes interval and 0.5 to 2 km spatial resolution
  - 16 channels – Visible (0.06 μm), Water vapor (6.04 μm), and Infrared (10.5 μm) channels
- **KMA Weather Radar**
  - 5-minutes interval and 0.5 km spatial resolution
- **Test Case: Typhoon Hinnamnor**
  - 2022/09/05 0100 to 0700 UTC

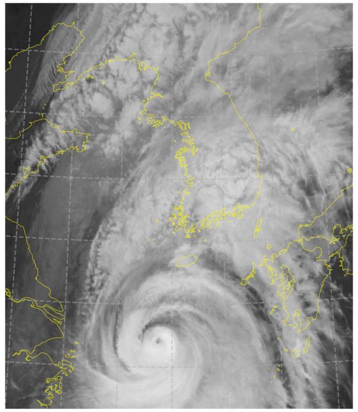
(a) VIS 0.06



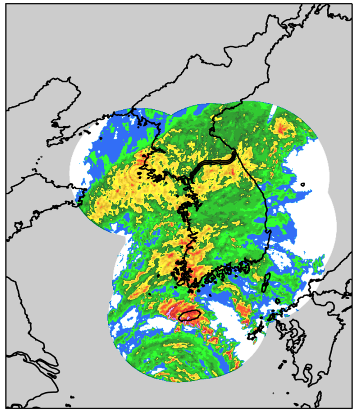
(b) WV 6.04



(c) IR 10.05



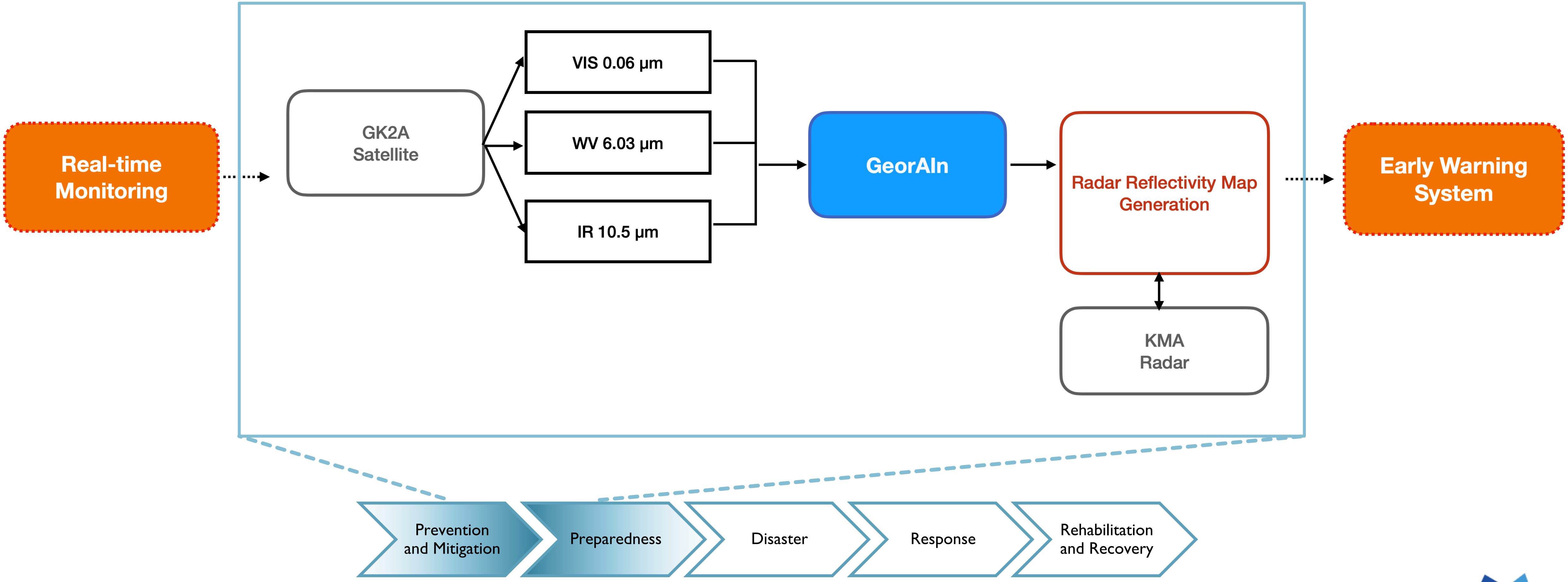
(d) Radar



*KMA: Korean Meteorological Administration

Disaster Monitoring Model

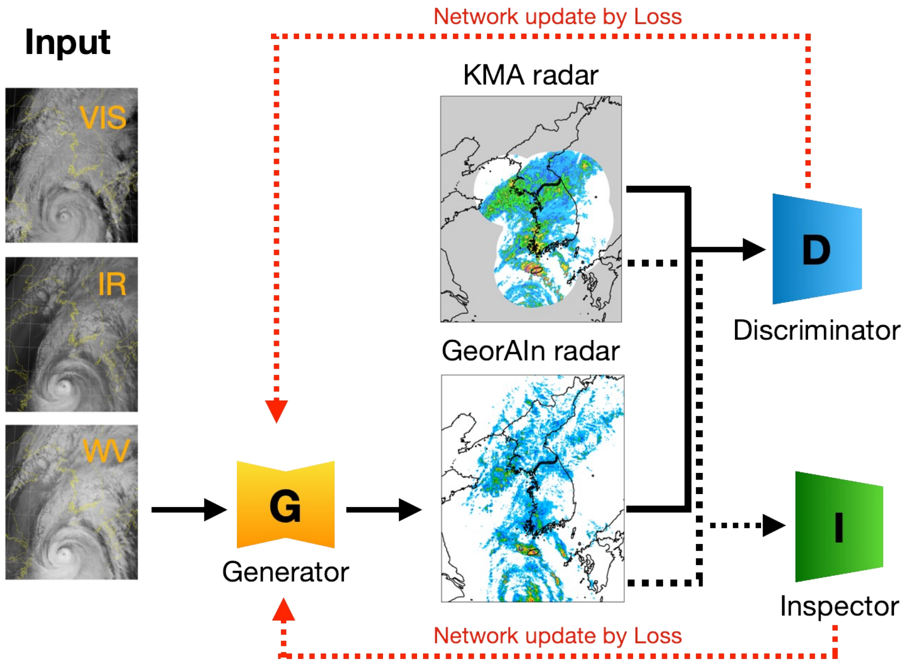
- two-step process, consists of WR-Net and GeorAIn
  - Rain forecasting over the next few hours for early warning



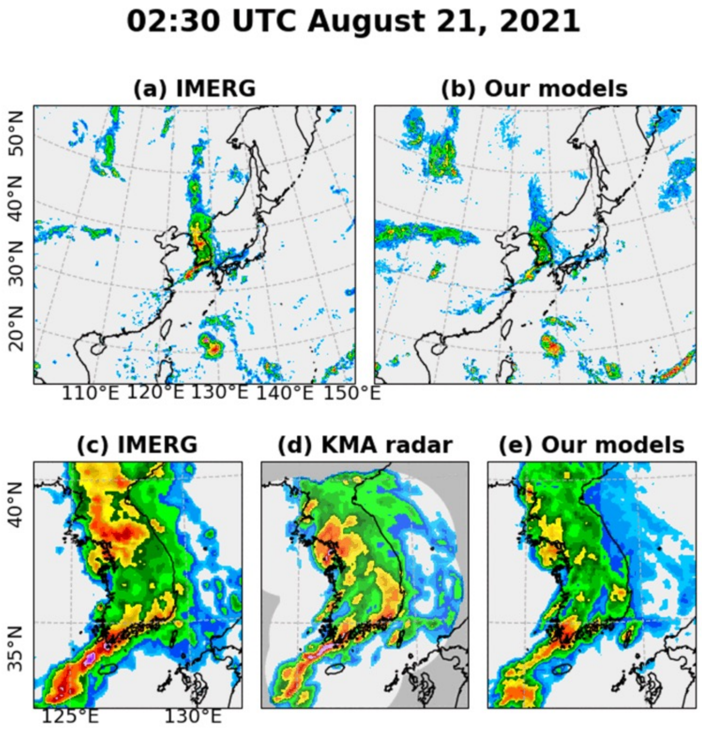
Overview of disaster management process

Disaster Monitoring Model

- **Generative Adversarial Network for rain – GeorAIn**
  - Generate proxy radar reflectivity map using Pix2PixCC model ([6])
  - Inspector guides the generated image to be physically consistent with the real image



Overview of GeorAIn [5]

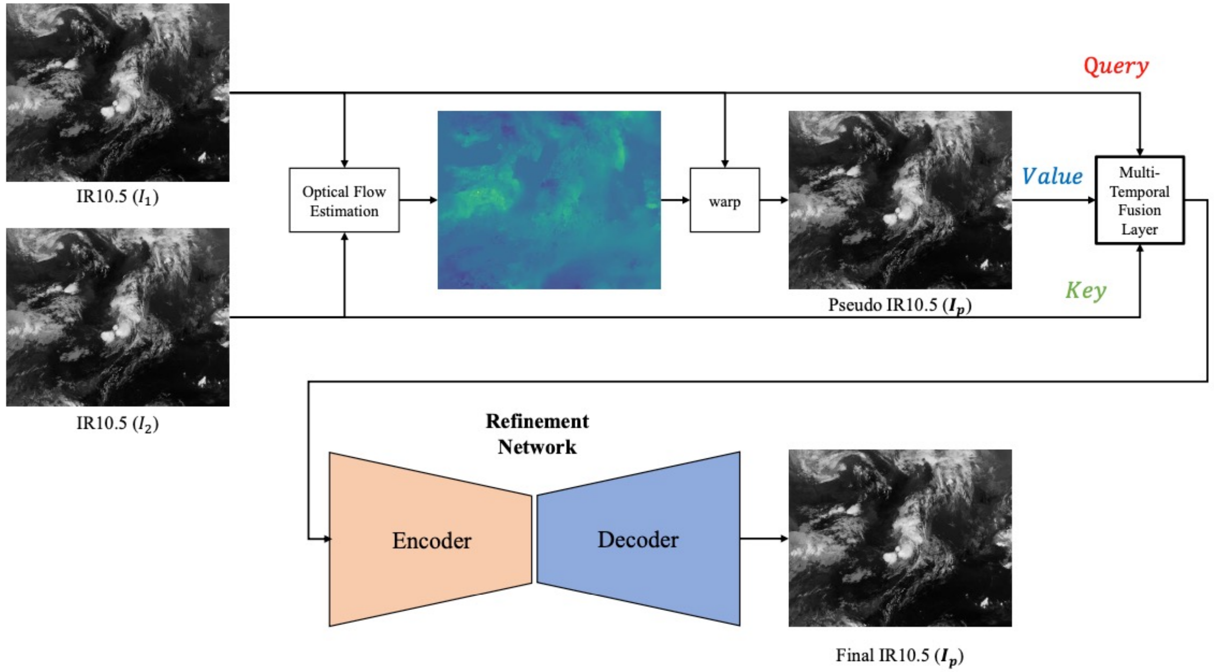


Qualitative results of GeorAIn [5]

[5] Yim et al. "Global Radar Precipitation Map Generation from Integrated Geostationary Satellite Products Using Deep Learning Approaches." (AMS, 2023).
[6] Jeong, Hyun-Jin, et al. "Improved AI-generated Solar Farside Magnetograms by STEREO and SDO Data Sets and Their Release." *The Astrophysical Journal Supplement Series* 262.2 (2022): 50.

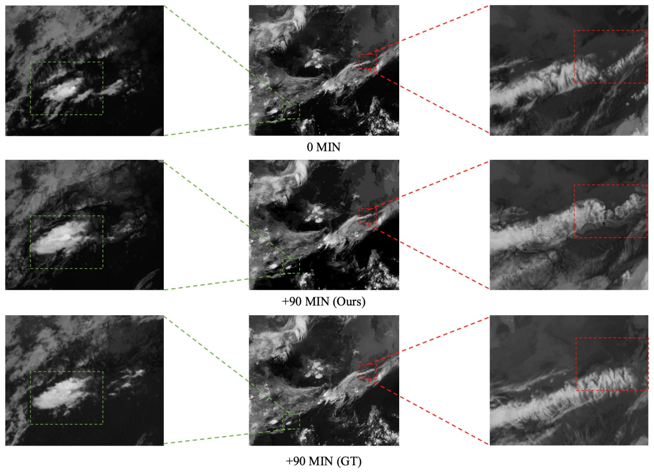
Disaster Monitoring Model

- **Video Frame Prediction Network – Warp and Refine Network (WR-Net)**
  - Warping component for extracted optical flow
  - Refinement component for intensity changes of each pixel



Overview of WR-Net [7]

Method	Channels	PSNR ↑	SSIM ↑
Linear	IR	38.667	0.745
SSM-T	IR	43.285	0.831
WR-Net (Warp Only)	IR	44.213	0.904
WR-Net (Full)	IR	**46.527**	**0.934**

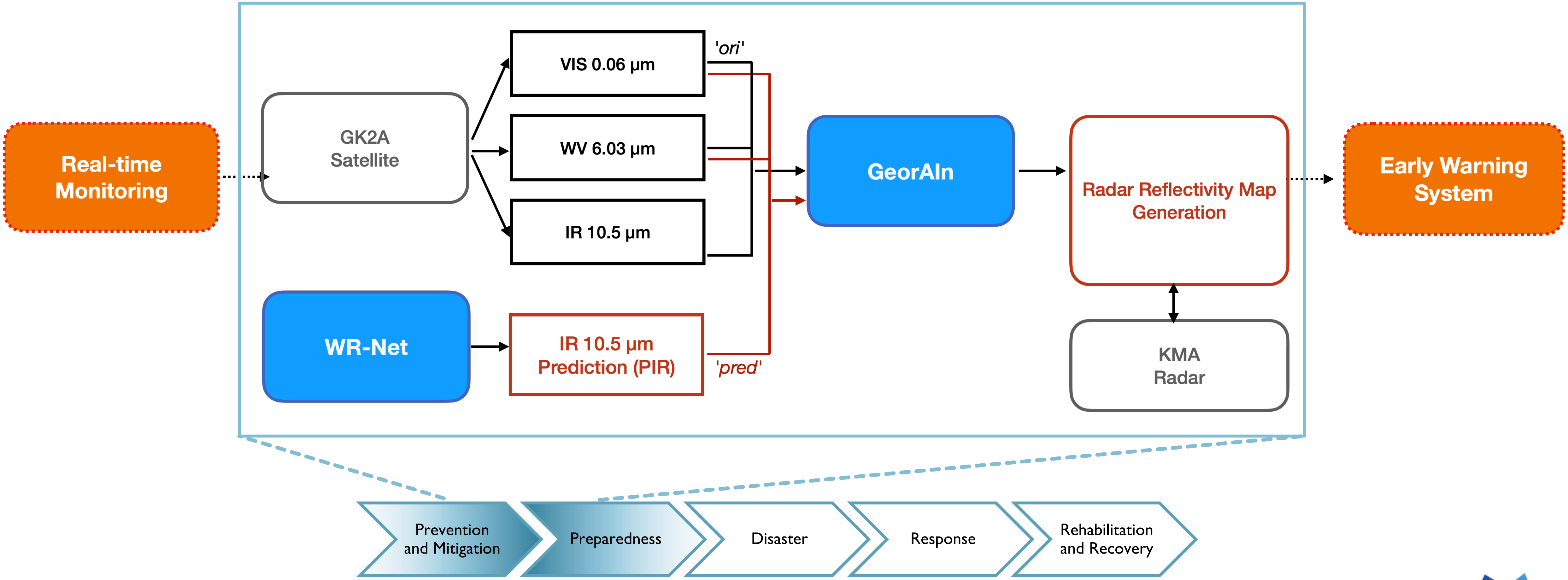


Qualitative results of WR-Net [7]

[7] Seo et al. "Intermediate and Future Frame Prediction of Geostationary Satellite Imagery With Warp and Refine Network." *arXiv preprint arXiv:2303.04405* (2023).

Disaster Monitoring Model

- two-step process, consists of WR-Net and GeorAIn
  - Rain forecasting over the next few hours for early warning



Overview of disaster management process

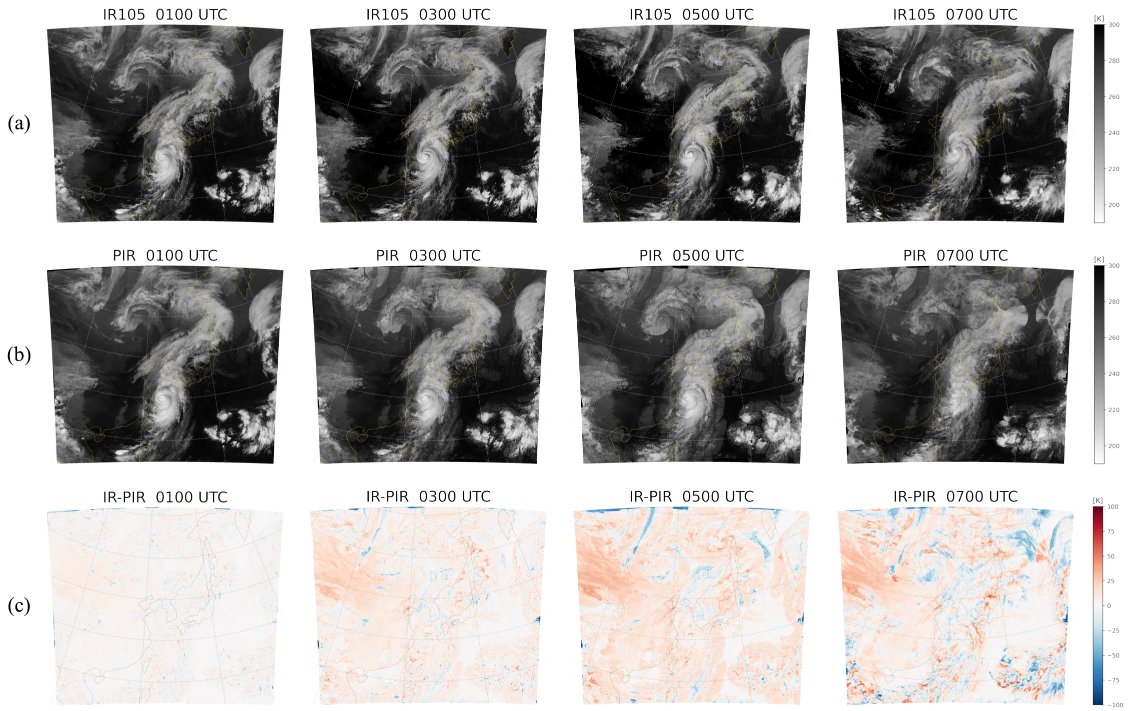
Chapter 03

Results

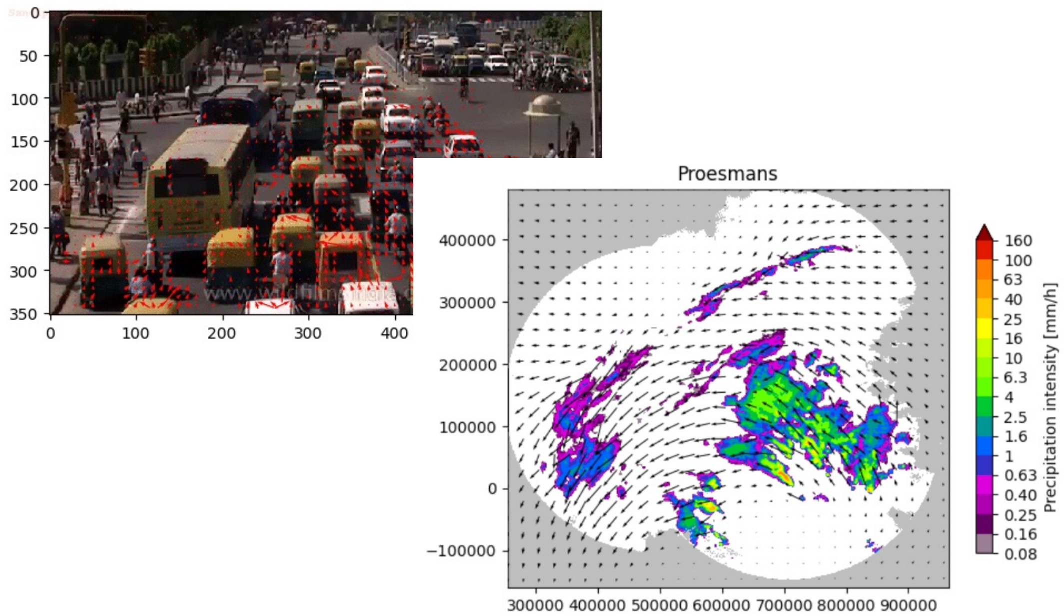
Results: Hinnamnor Case Study

1) Predicting satellite images from WR-Net

- WR-Net prediction images preserve cloud locations and shapes compared to the original (GK2A) image
- The predicted clouds are divided and dimmed by the reduced cloud amount (limitation of optical flow)



IR images from (a) GK2A and (b) WR-Net predicted result, and difference map between them.

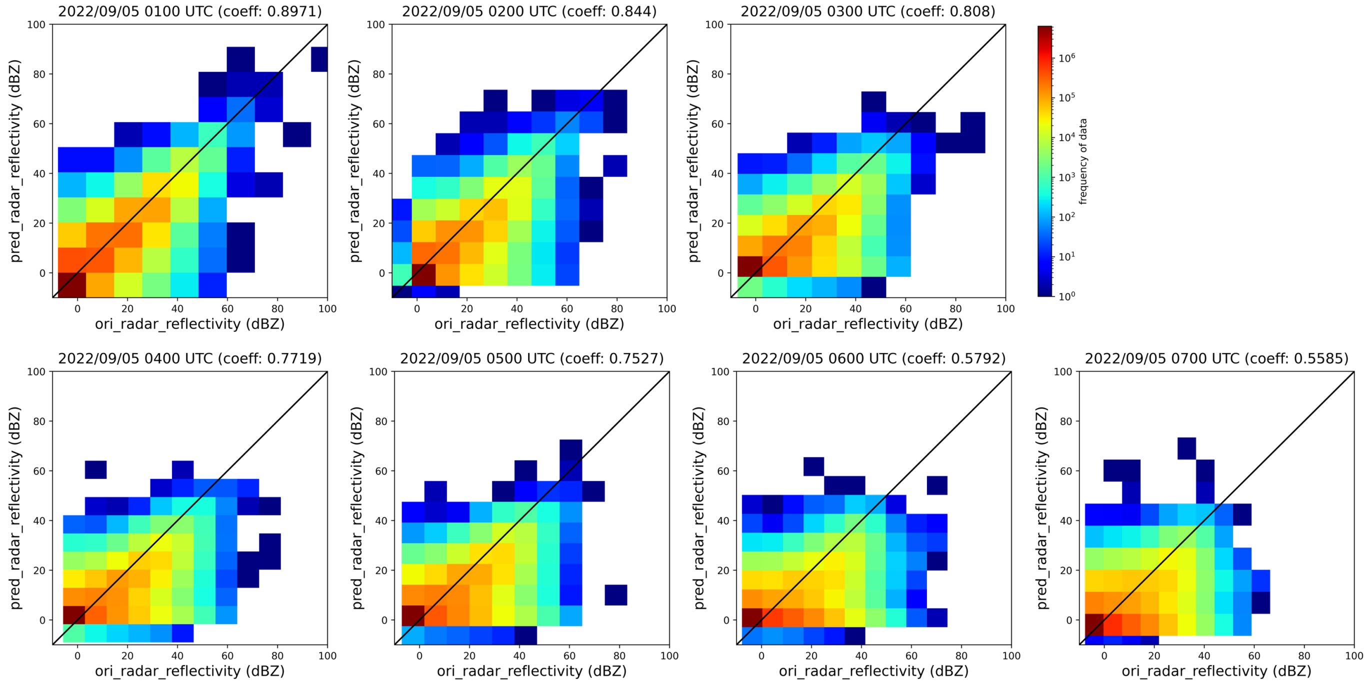


Optical flow only detect the movement and intensity of objects, act as wind vector in weather task

Results: Hinnamnor Case Study

2) Generating radar reflectivity by GeorAIn

- Shown a high correlation coefficient of over 0.8 at the future 3 hours and 0.75 at 5 hours
- ‘*Pred*’ results tend to underestimate the radar reflectivity more than the ‘*Ori*’ results



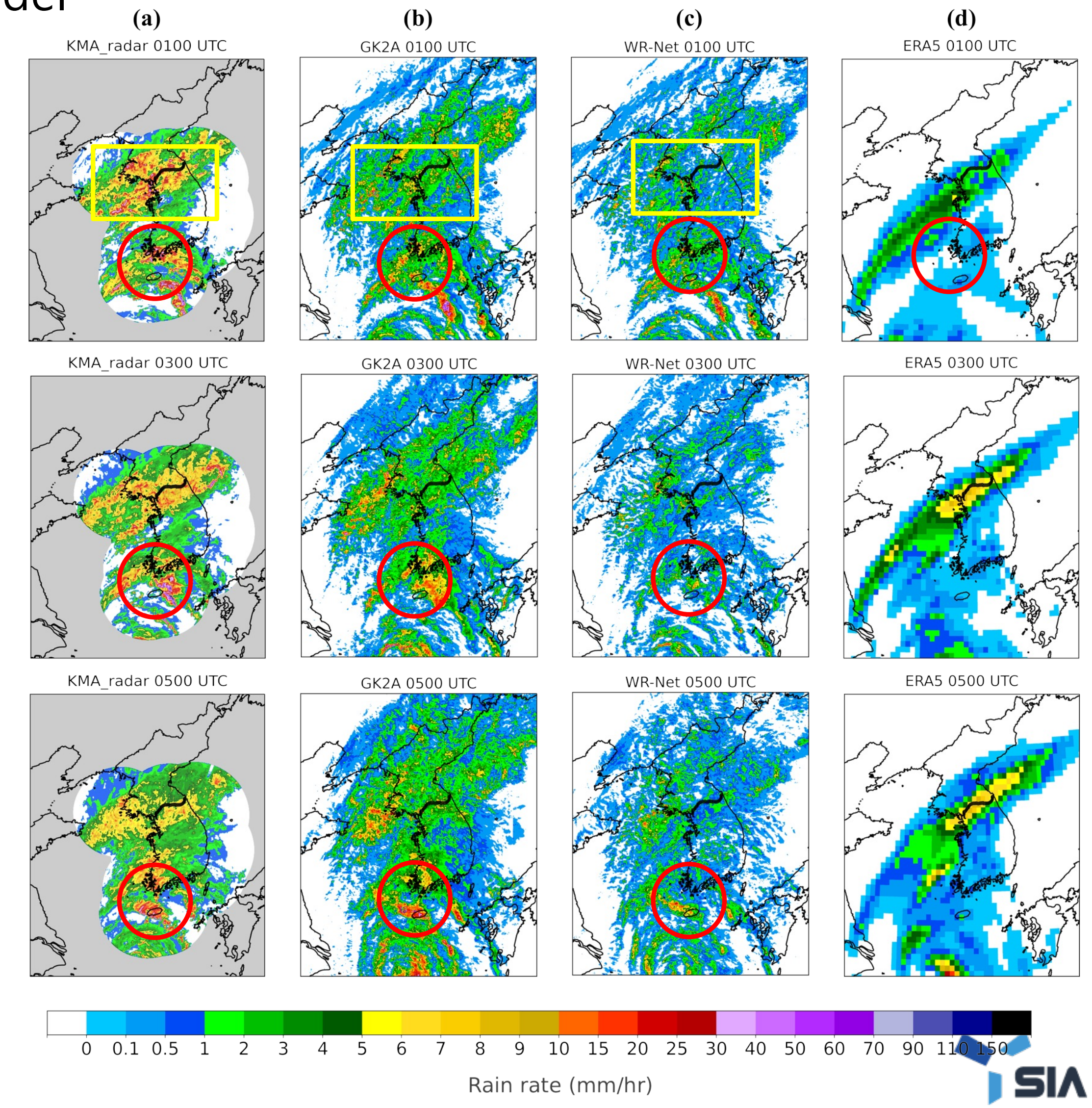
* Convert the radar reflectivity to rain rate by using the Z-R relationship: $Z = 200R^{1.6}$

The 2D histogram of the radar reflectivity from the GeorAIn results
- ‘*ori_radar_reflectivity*’ is the result of original GK2A three channels (VIS, WV, and IR)
- ‘pred_radar_reflectivity’ is the result of two GK2A channels (VIS, WV) and one WR-Net predicted channel (PIR)

Results: Hinnamnor Case Study

3) Monitoring Typhoon rainfall by disaster monitoring model

- Compared with (a) KMA radar, (d) Reanalysis data – ERA5
- (b) GeorAIn result and (c) GeorAIn + PIR from WR-Net
- Our results show similar patterns with radar, but free of spatial constraints (masked areas in (a))
- Our results are highly accurate in heavy rainfall area (red circle) and slightly underestimated in the moderate rainfall area (yellow box)



Chapter 04

Conclusion

Conclusions

- We predict rainfall in Typhoon Hinnamnor case by our disaster monitoring model with geostationary satellite images
- We utilize the WR-Net results as the input data of the GeorAIn model to predict future rainfall
- The GeorAIn results show our model can predict the accurate timing, location, and intensity of heavy rain area

- We expect our results to help communicate preemptive and precise warning systems
- We plan to expand our disaster monitoring model to flood and storm cases on the global scale

Thank you for attention

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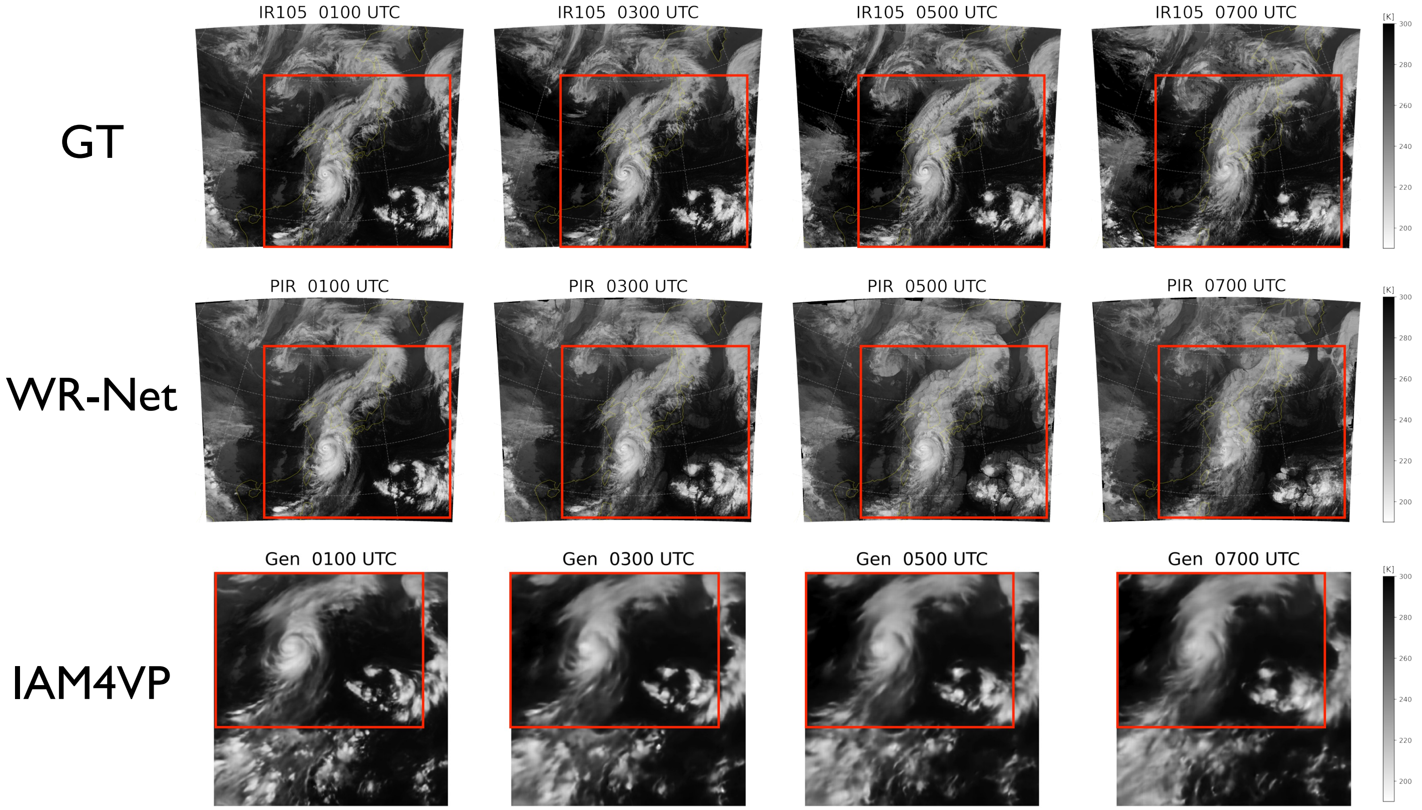
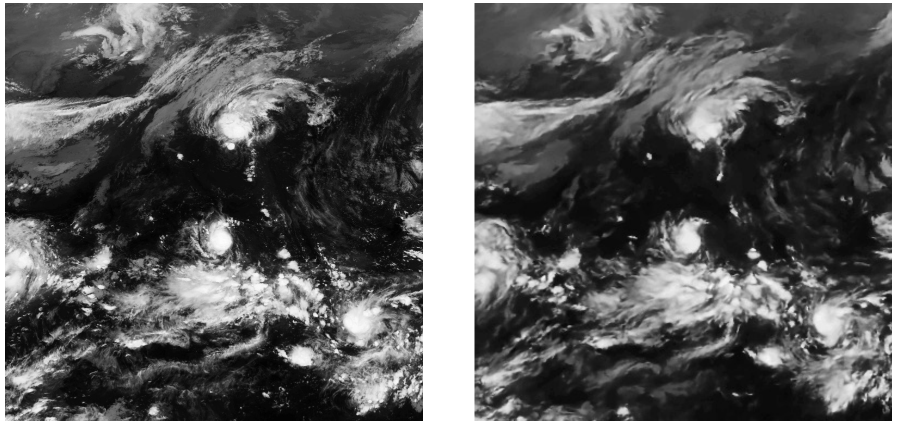
Appendix

- Improved video prediction model: IAM4VP [8]
  - Solving the diminishing problem and generating new cloud cells



Typhoon Forecasting with IAM4VP model

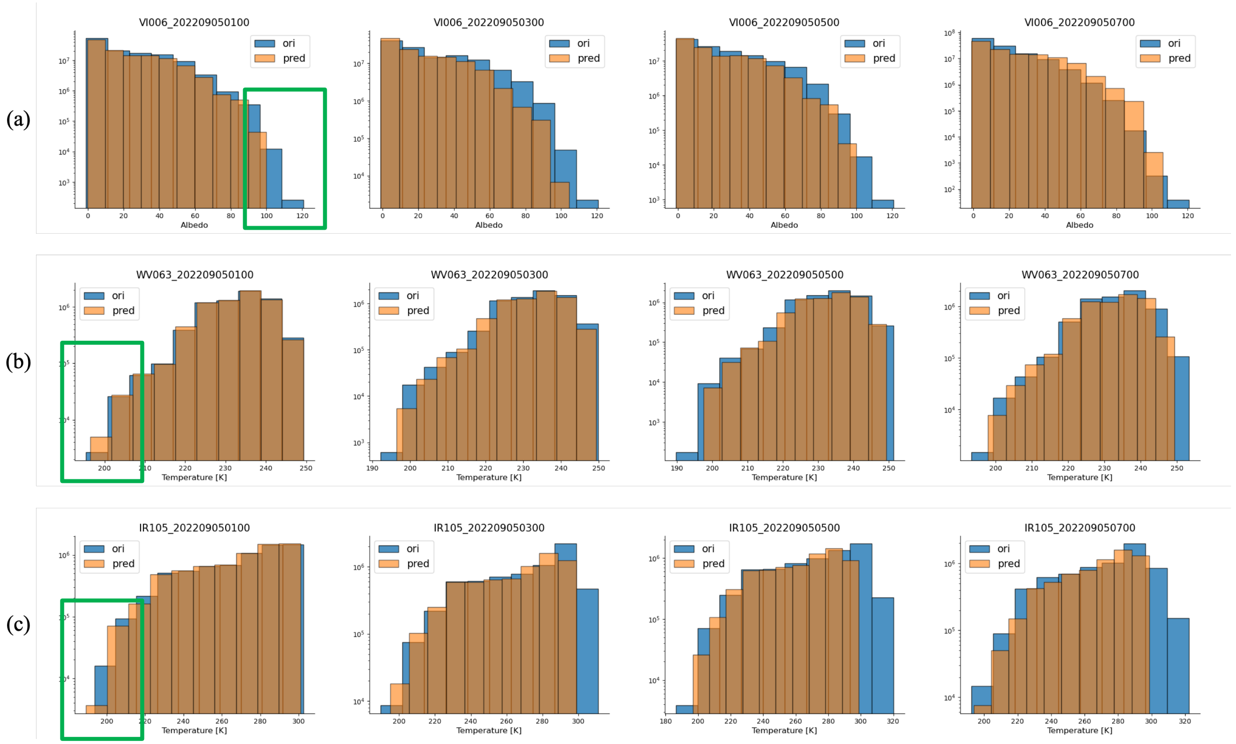


GT IAM4VP + SR

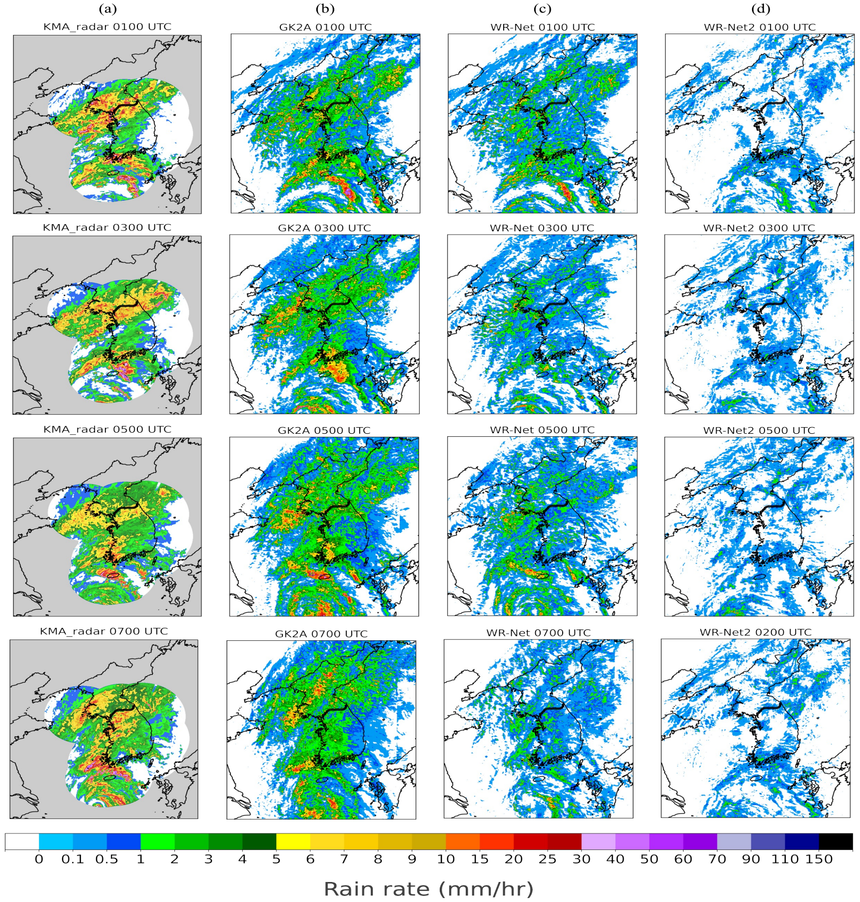
[8] Seo, Minseok, et al. "Implicit Stacked Autoregressive Model for Video Prediction." *arXiv preprint arXiv:2303.07849* (2023).

Appendix

- Replacing three channels with WR-Net



Comparison histograms of each channel. (a) is visible 0.06 µm, (b) is water vapor, 6.04 µm and (c) is infrared 10.5µm channels. The Blue bar means GK2A image and the Brown bar is WR-Net predicted image.



Qualitative results of each input combination.
(a) KMA radar, (b) GK2A three channels, (c) two GK2A channels + one WR-Net result, and (d) three WR-Net results

Appendix

- Training information – WR-Net and GeorAIns

	WR-Net	GeorAIn
Training data	GK2A 2020.08-2021.07, 2 min	GK2A 2019.08-2021.07. 10 min
Base model	TV-L1 algorithm (optical flow)/ U-Net based VGG16 (refinement)	Pix2PixCC model
Loss function	PSNR, SSIM	LSGAN, FM loss, CC loss
Optimizer	Adam	Adam
Learning Rate	1e-4	0.0002