人工智慧降尺度技術在氣候服務中的應用發展策略

李清縢[1]、陳昀靖[1]、王志嘉[1]、林昀靜[1]、王則燊[1]、朱芸霆[1]、劉祉筠[1]、洪景山[1]、張惠玲[1]、羅資婷[1]、潘琦[1]、曾琬鈴[2]、王科植[3]

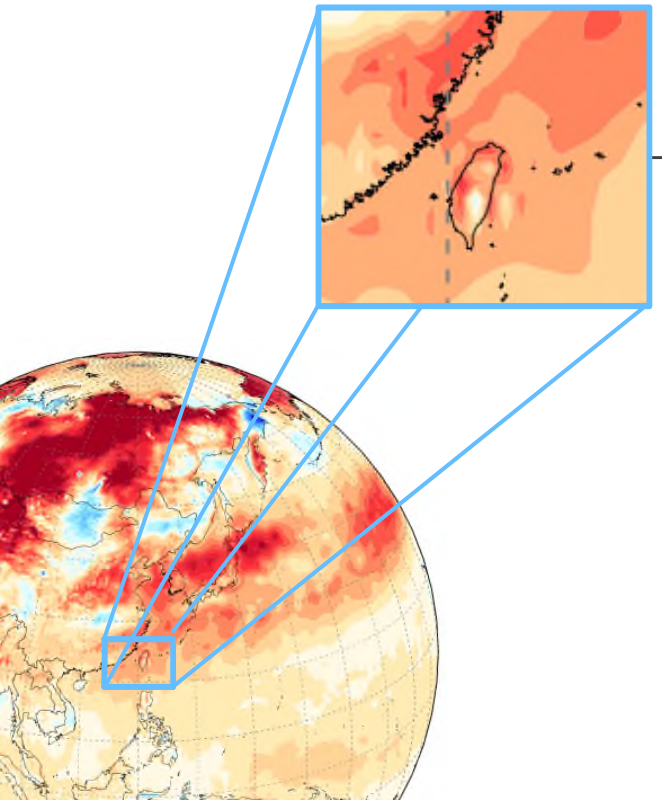
[1]中央氣象署、 [2]國立臺灣大學、 [3]國立臺灣師範大學

114年第39屆天氣分析與預報研討會

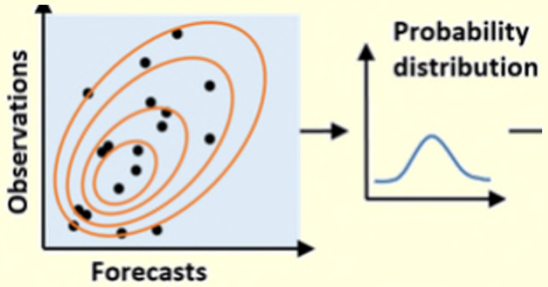
Central Weather Administration

The Role of Post-Processing in climate application

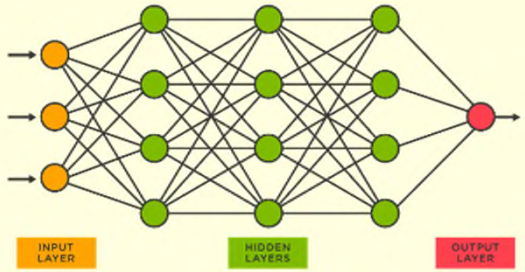
Global Forecasts



Downscale and Bias correction

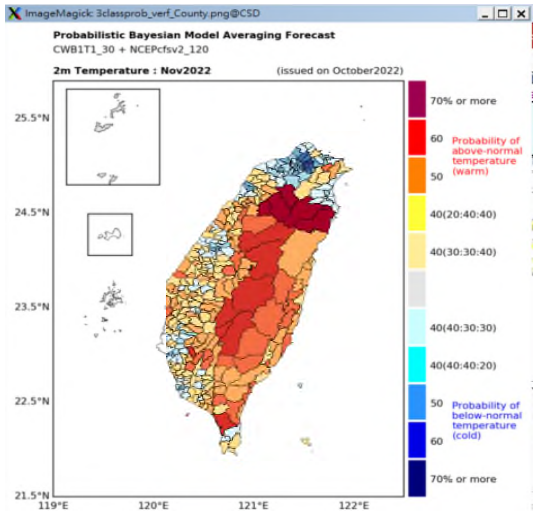


Statistical Post Process
- Downscaling/Bias Correction



AI Downscaling Emulator
(CorrDiff)

City/Township Forecast products



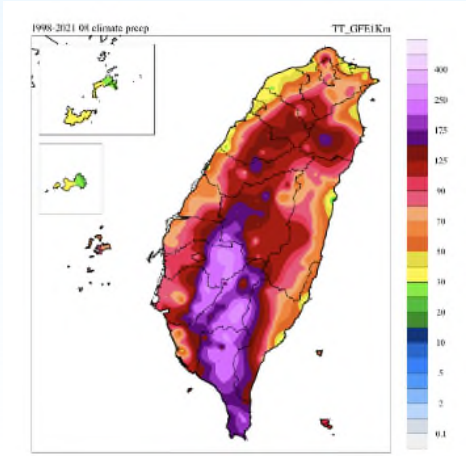
Cross-Sector Applications

Rich data: potential for AI-ready data in CWA

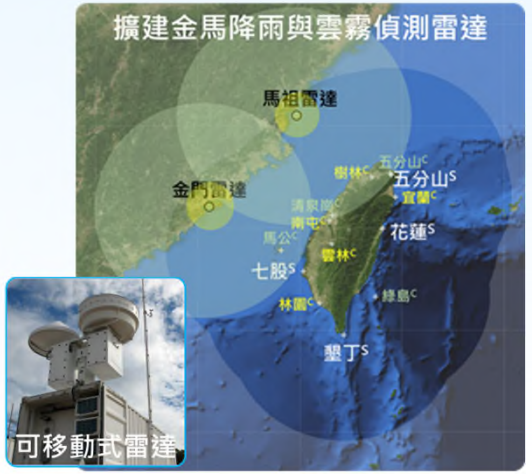
Observation

In-situ

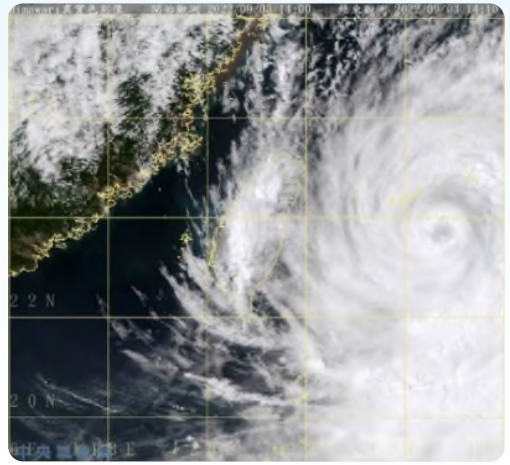
Gridding(1km)



Radar

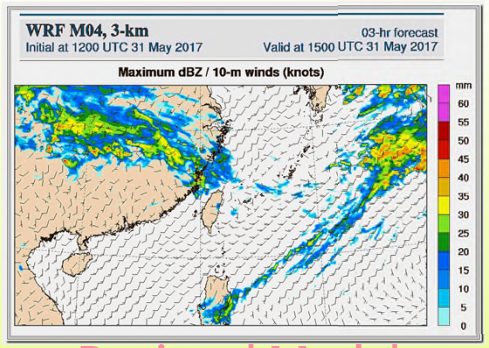


Satellite

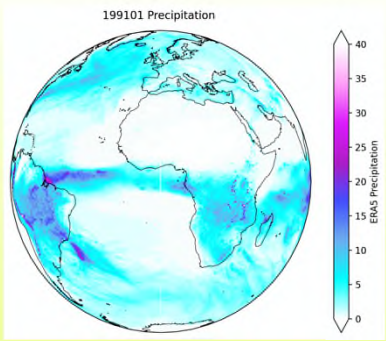


Grid Data

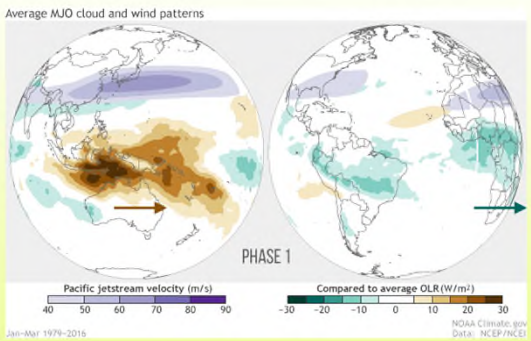
0~5day | 16day | 45day | 9month



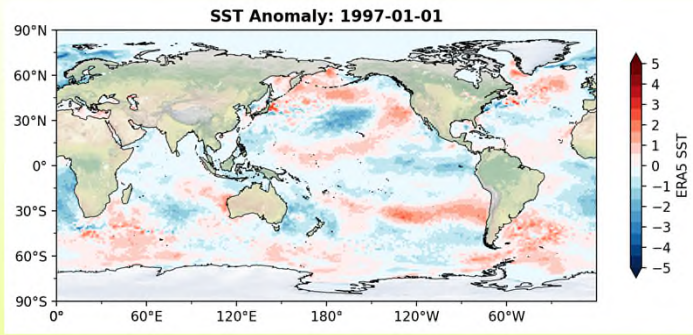
Regional Model
(15/3/1 km resolution)



Global Model
(25 km resolution-> 13 km in 2025)



Extended weather (S2S)
(28 km resolution)



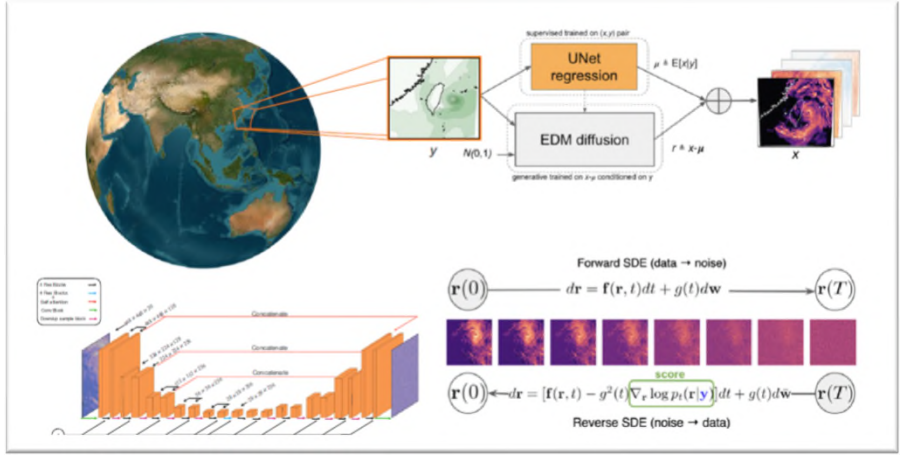
Short-term climate model
(60 km resolution)

Example: AI/ML downscale in CWA

3. Generative Correction Diffusion Model (CorrDiff)

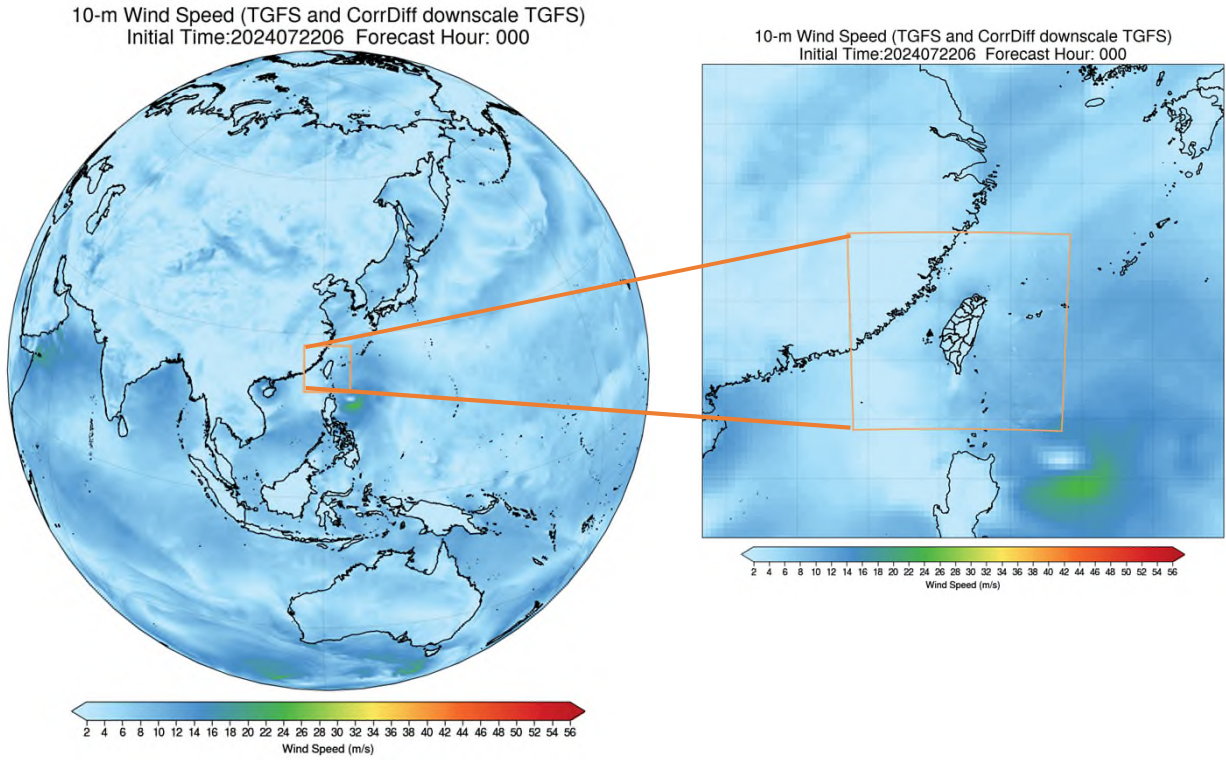
Training Data

- **Global data: ERA5 reanalysis**
  a) 25-km resolution
  b) 850-hPa and 500-hPa U, V, T, height,
  c) U10, V10, T2, column water vapor
- **Regional data: CWA RWRF analysis**
  a) 2-km resolution
  b) U10, V10, T2, (simulated) maximum radar reflectivity
- **Collaboration between CWA and NVIDIA**



Morteza Mardani et al., 2025: Residual corrective diffusion modeling for km-scale atmospheric downscaling. https://doi.org/10.1038/s43247-025-02042-5.

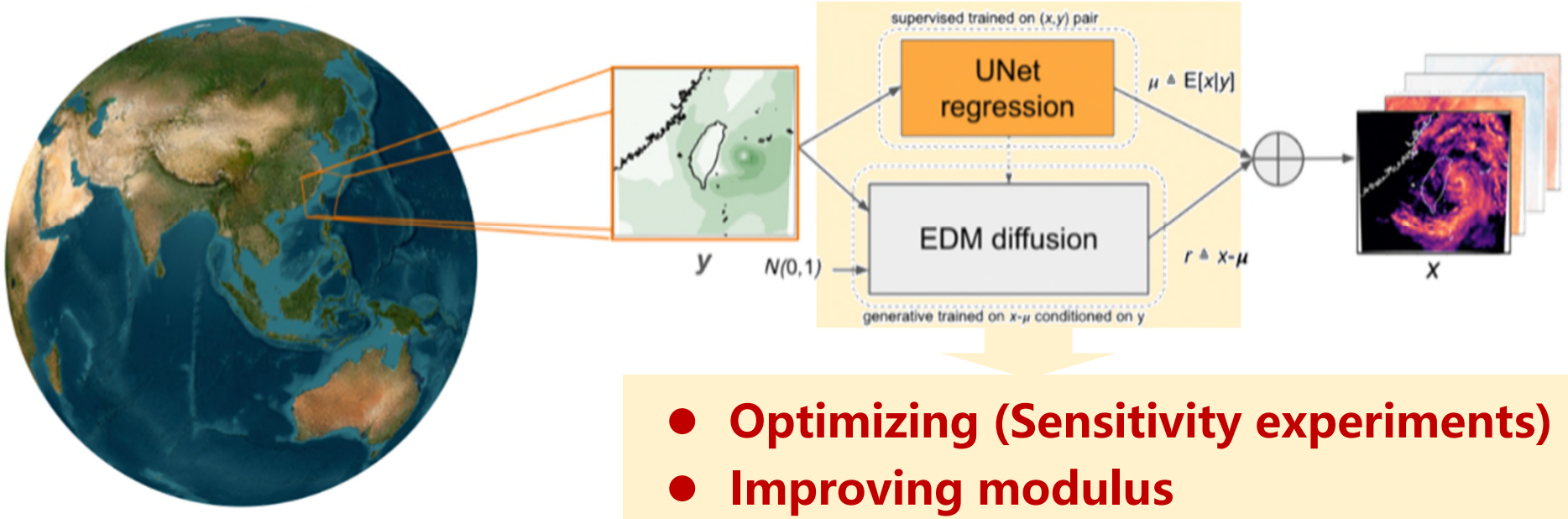
■ **Typhoon Gaemi: CorrDiff downscaled from global NWP forecast**



Current Limitation:

- **Limited training data (only 4 years)**
- **No direct precipitation output**
- **Terrain effects not included**

Improving and Optimizing CorrDiff model



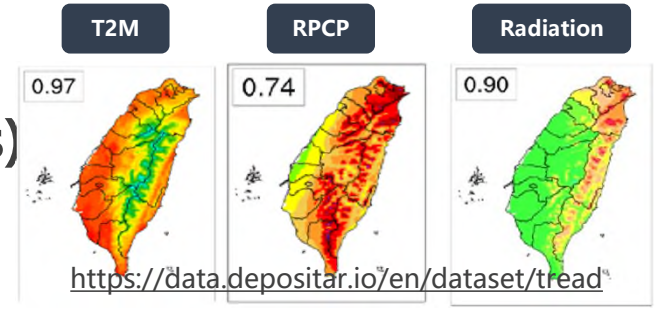
- **Optimizing (Sensitivity experiments)**
- **Improving modulus**

【Collaboration between CWA，NTNU, NTU and NVIDIA】

Training Data	Spatial resolution	Training	Testing	Surface variables	Pressure level variables
ERA5 (Global Data)	25 km	1991-2015	2016-2023	Precipitation,T2M, U10M, V10M	850-hPa and 500-hPa U, V, T, Z
TReAD (Regional Data)	2 km	1991-2015	2016-2023	Precipitation,T2M, U10M, V10M	
TaiSA (Regional Data)	1km	1998-2015	2016-2023	Precipitation,T2M	

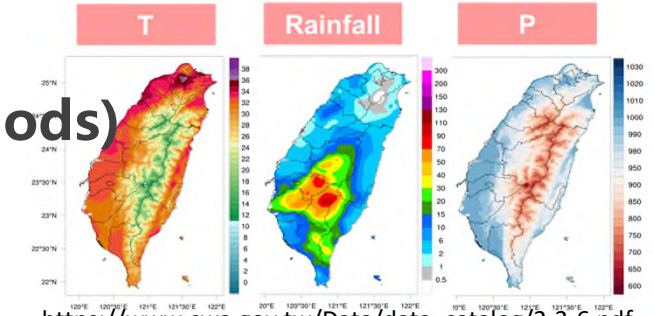
Taiwan high-resolution Data

- **Taiwan Re-Analysis Downscaling (TReAD) Data**
  (Dynamically downscaling using WRF model from ERA5 re-analysis)
  - **2-kilometer resolution, hourly output**
  - **Period: 1979 - 2023. (45 years)**



https://data.depositar.io/en/dataset/tread

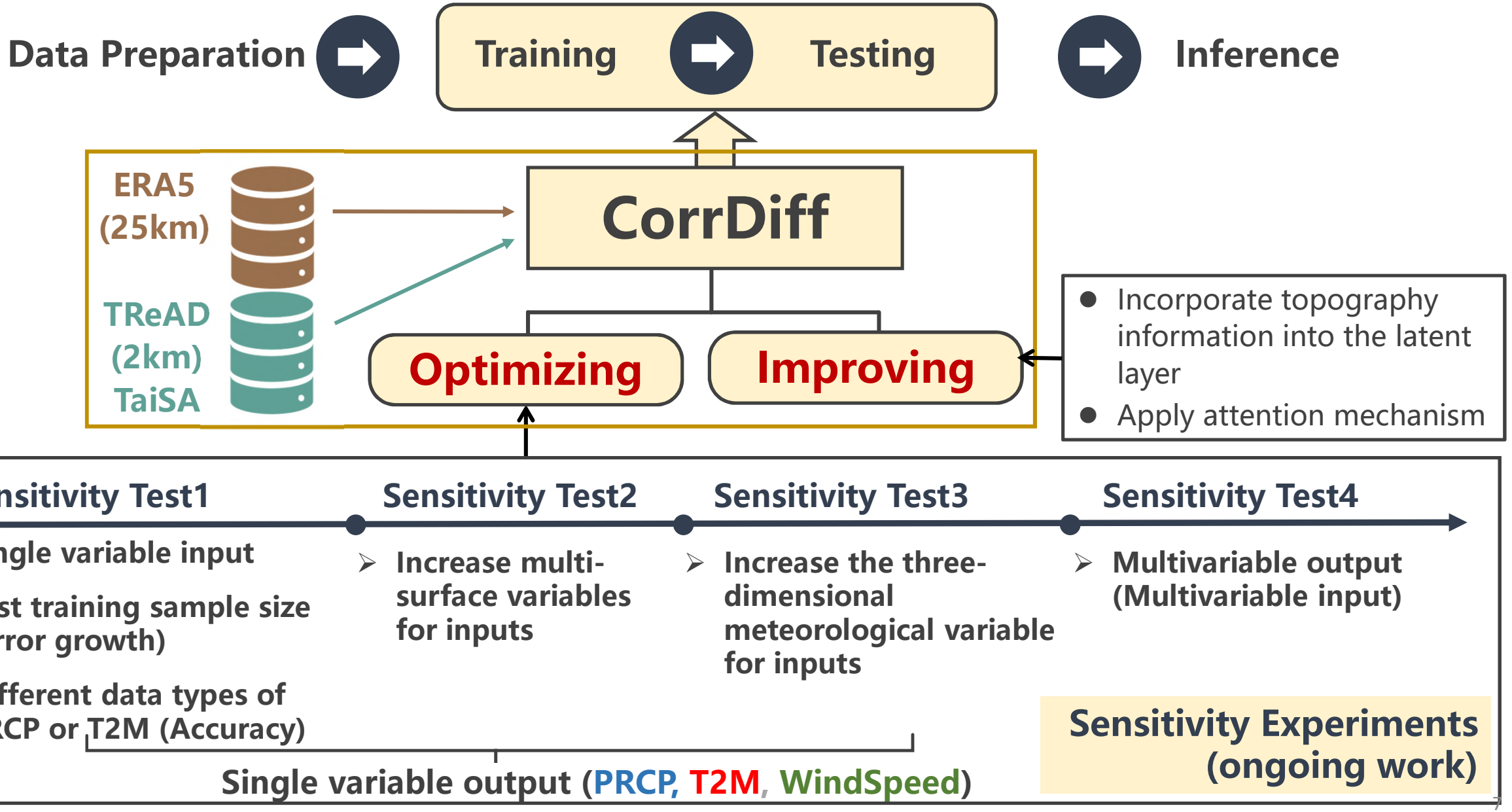
- **Taiwan Station-based Analysis (TaiSA) Data**
  (Transforming station data into gridded data using statistical methods)
  - **1-kilometer resolution, hourly output**
  - **Period: 1998 - 2023. (25 years)**



https://www.cwa.gov.tw/Data/data_catalog/2-3-6.pdf

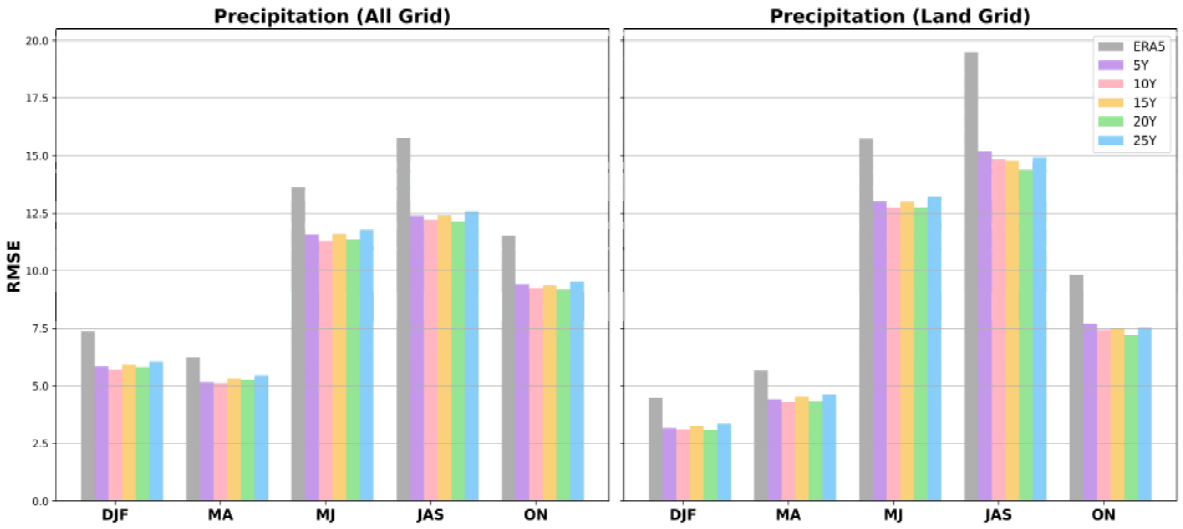
	TReAD Data	TaiSA Data
Strengths	• Dynamic consistent with model state variables • Well resolve the impact of high resolution terrain over 45 years	• Gridded observation data and climate consistency (ground truth)
Limitations	• WRF dynamic downscale, not ground truth	• Only surface variables (only land)

Experimental Design

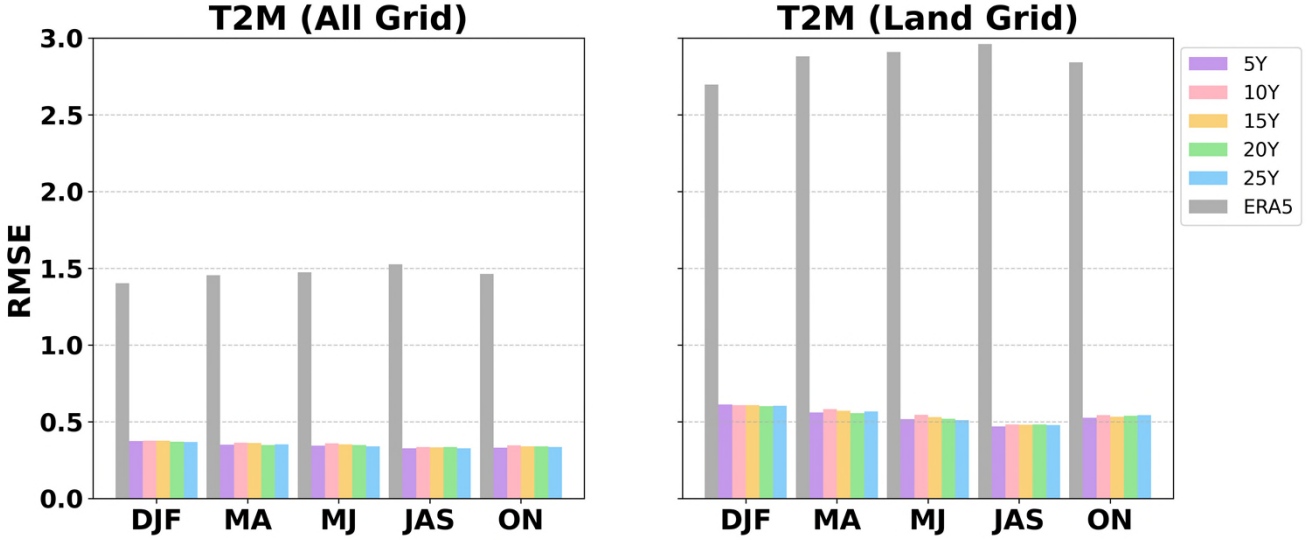


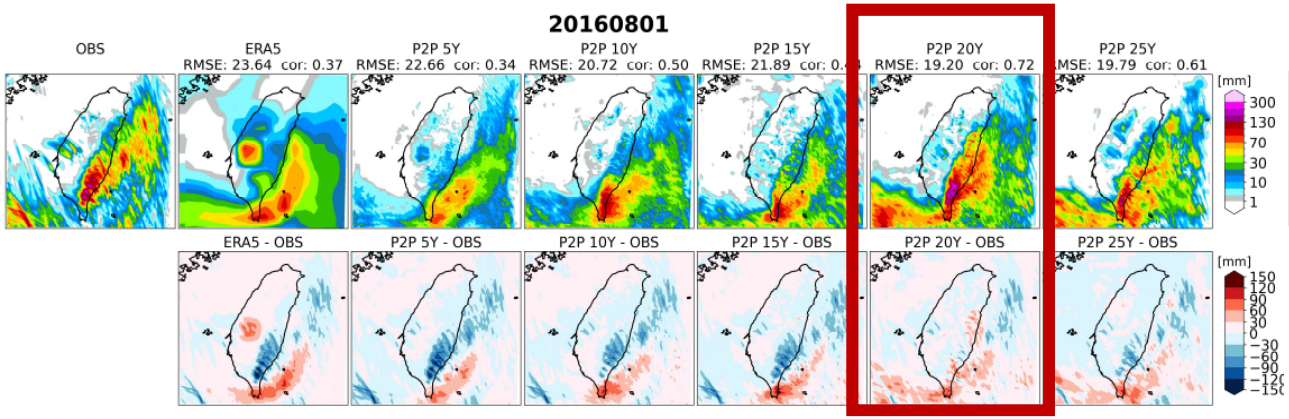
Error growth & Accuracy of sample size & types

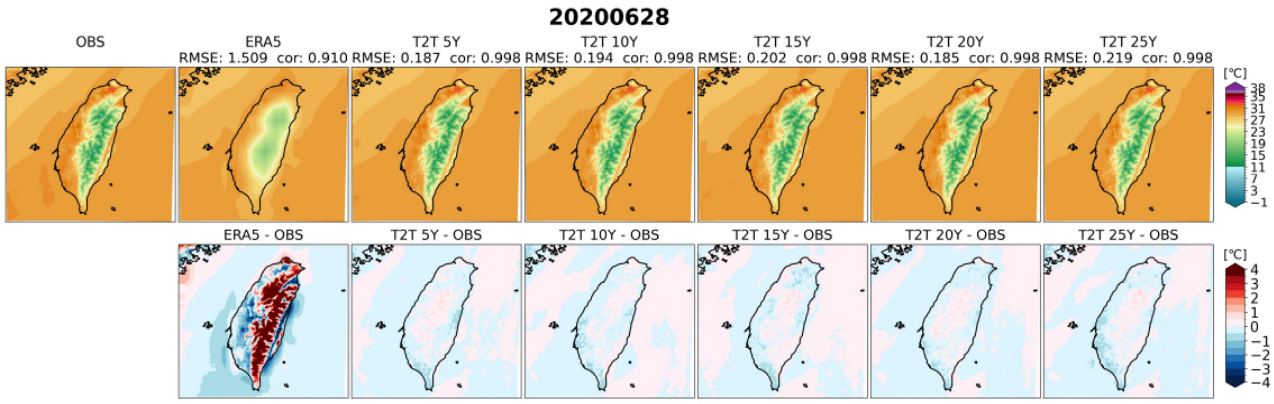
P2P : Input data: PRCP
Output data: PRCP



T2T : Input data: T2M
Output data: T2M

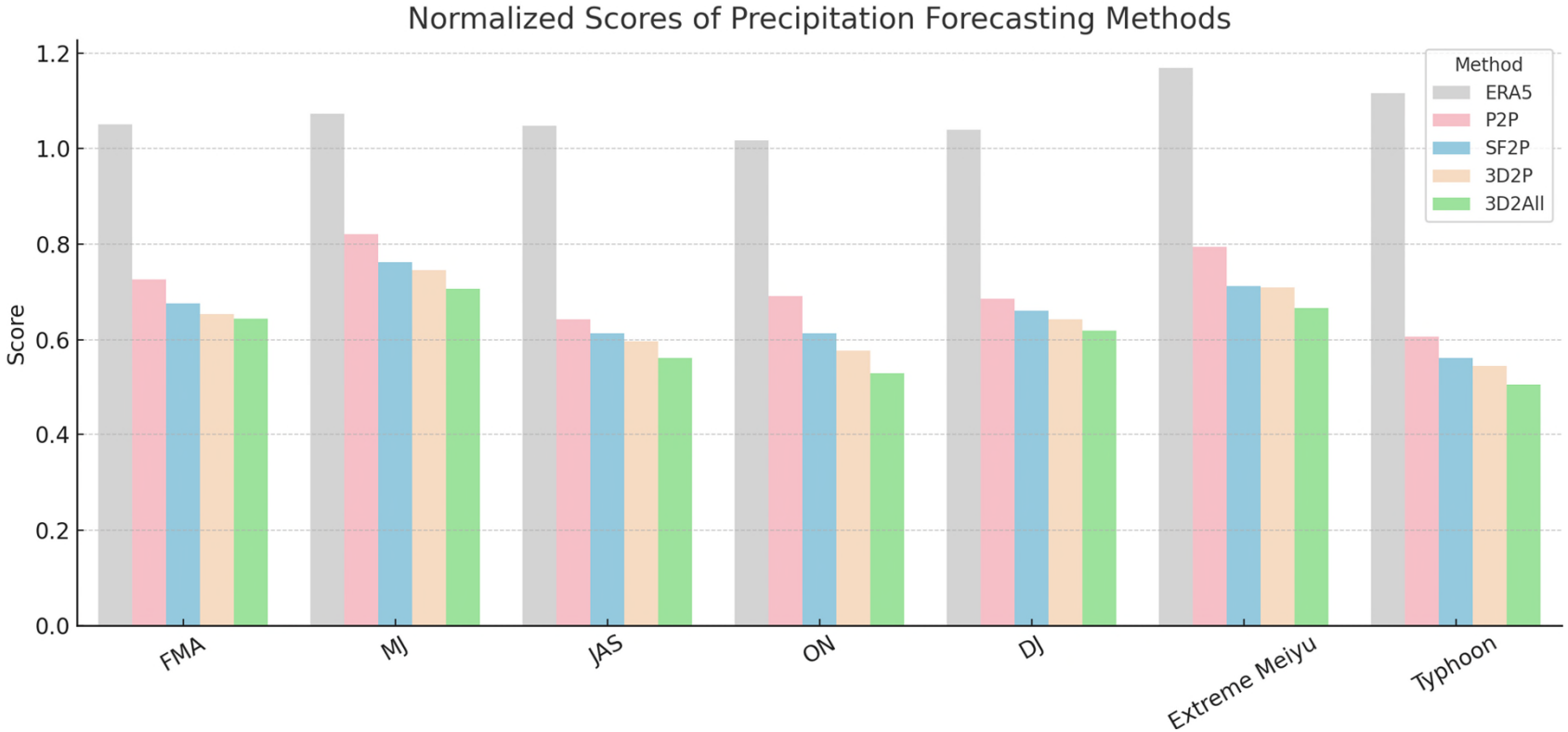






- **For Error Growth:**
  Precipitation requires 20 years of data to reach error saturation, Other meteorological variables (T2M or Winseppd), with near-normal distributions, show no significant error change with sample size.

Validation of single or multiple variables



P2P experiment:

Global data: Precipitation,
Regional data: Precipitation

SF2P experiment:

Global data:
Precipitation,T2M,U10M, V10M
Regional data: Precipitation

3D2P experiment:

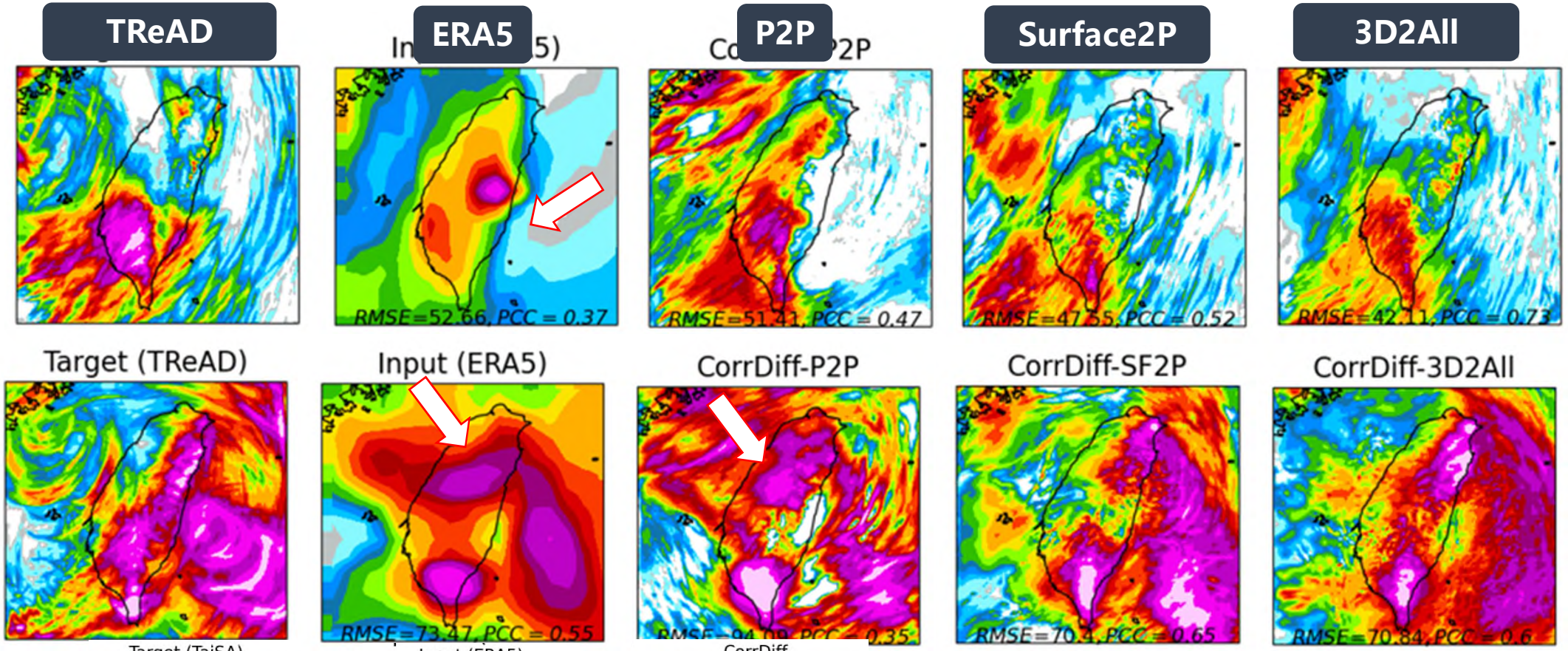
Global data:
Precipitation,T2M,U10M, V10M, Z, U, V, T at 925, 850, 700, 500mb
Regional data: Precipitation

3D2All experiment:

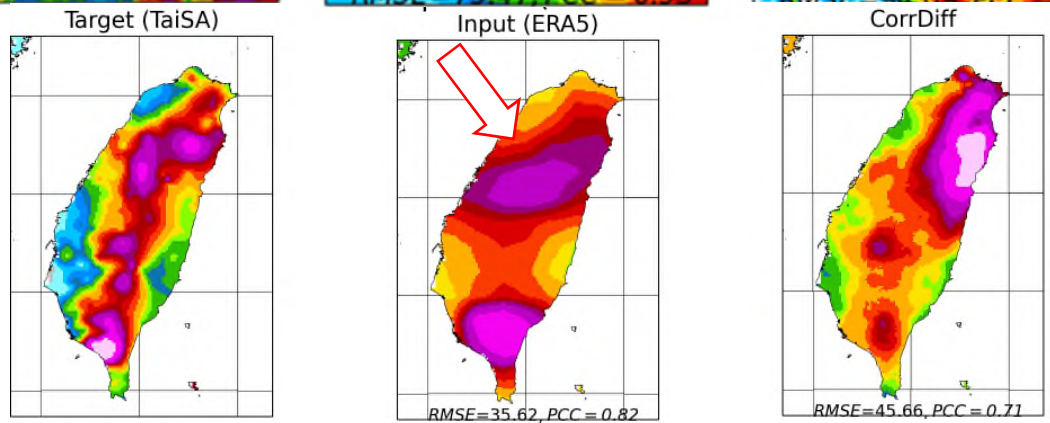
Global data:
Precipitation,T2M,U10M, V10M, Z, U, V, T at 925, 850, 700, 500mb
Regional data:
Precipitation,T2M,U10M, V10M

- Among all experiments, the 3D2All experiment demonstrates the best overall downscaling performance.

Case Study: CorrDiff Downscaling Performance



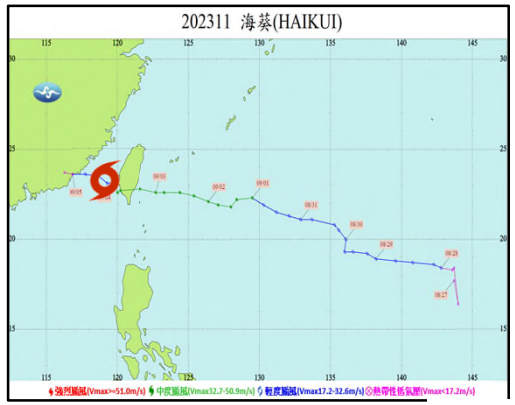
P2P experiment:
Global data: ERA5
Regional data: TaiSA



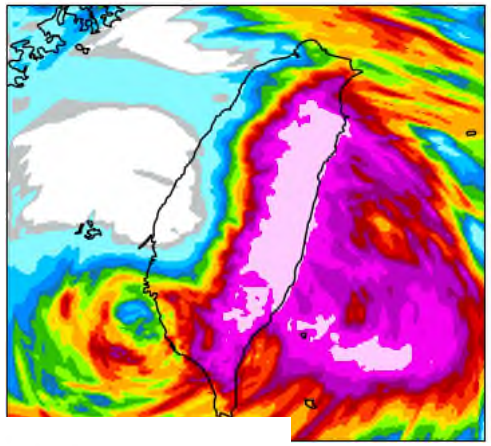
- This indicates that the corrdiff model has the potential to improve spatial rainfall accuracy compared to the raw ERA5 input.

Case Study: Typhoon Evaluation

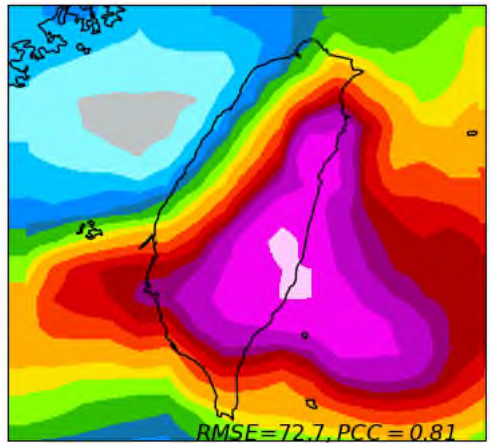
20230903
海葵 (HKIKUI)



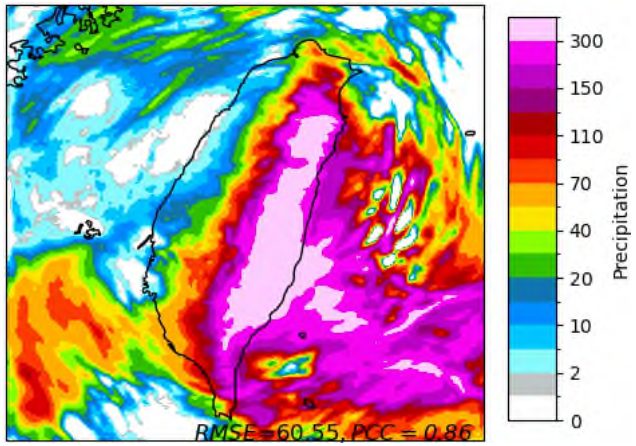
TReAD



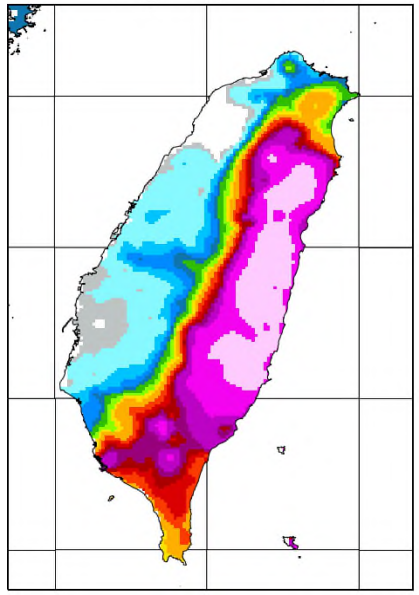
ERA5



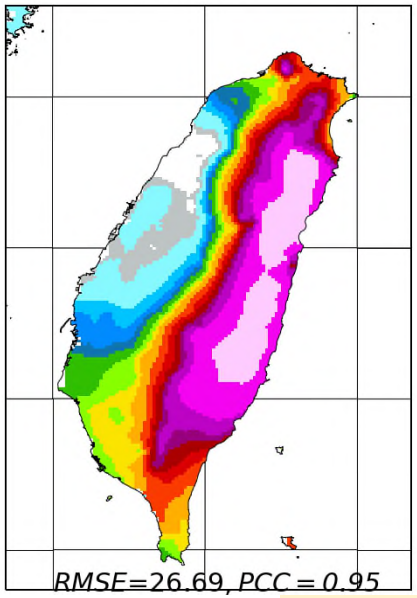
P2P



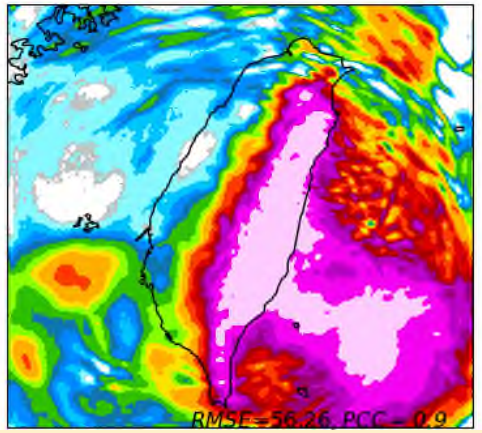
Target (TaiSA)



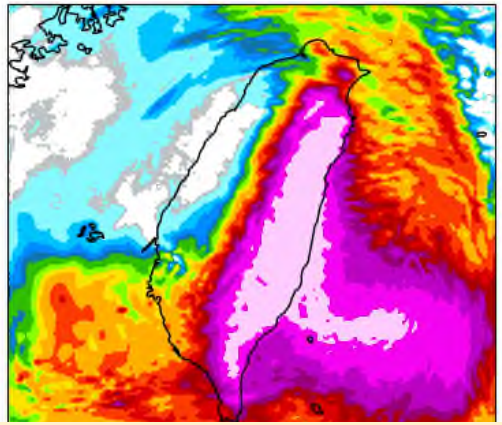
CorrDiff



Surface2P
CorrDiff



3D2All

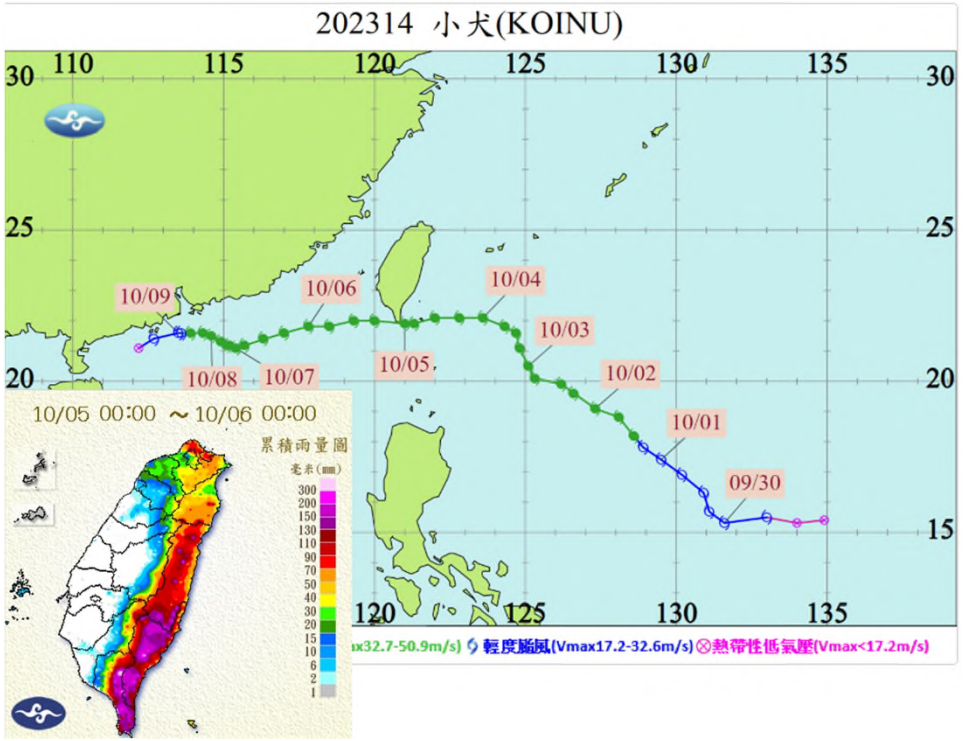


KUI typhoon case:

xperiments demonstrate rainfall pattern and amount are closer to TReAD than ERA5.

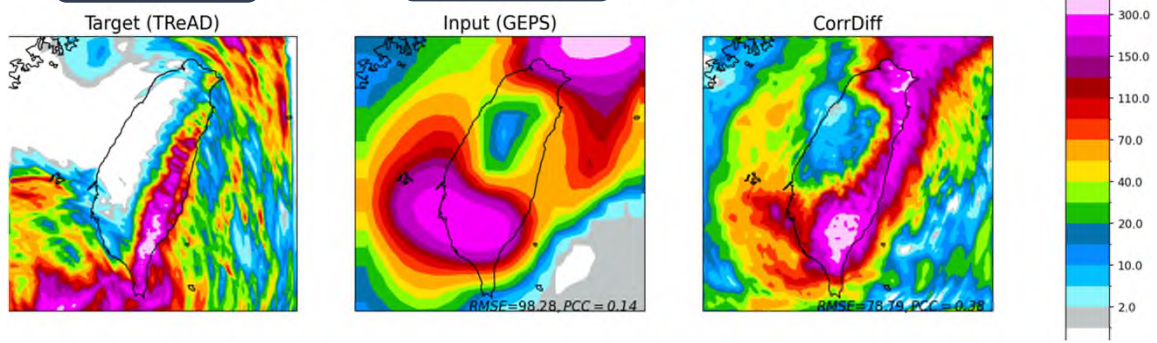
- However, Surface2P, 3D2P or 3D2All experiments does not significantly improve of rainfall accuracy.

Realtime CorrDiff Product (Test Bed)

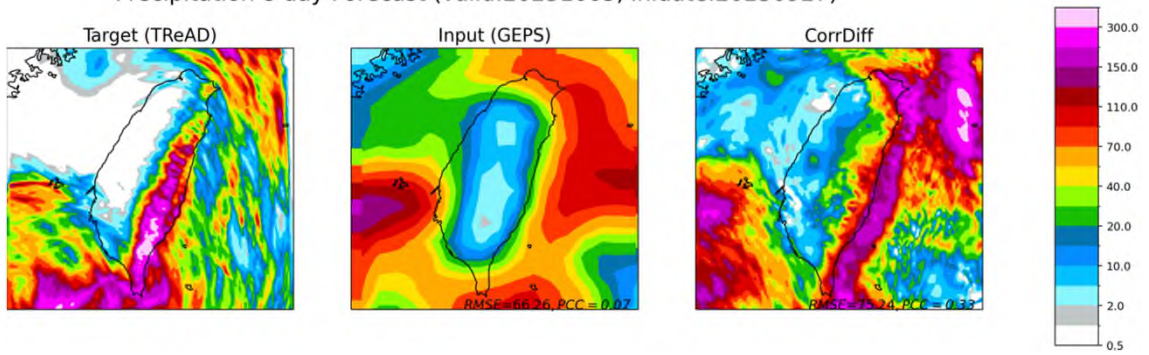


TReAD **GEPSv2** **SF2P**

Lead 4-Day

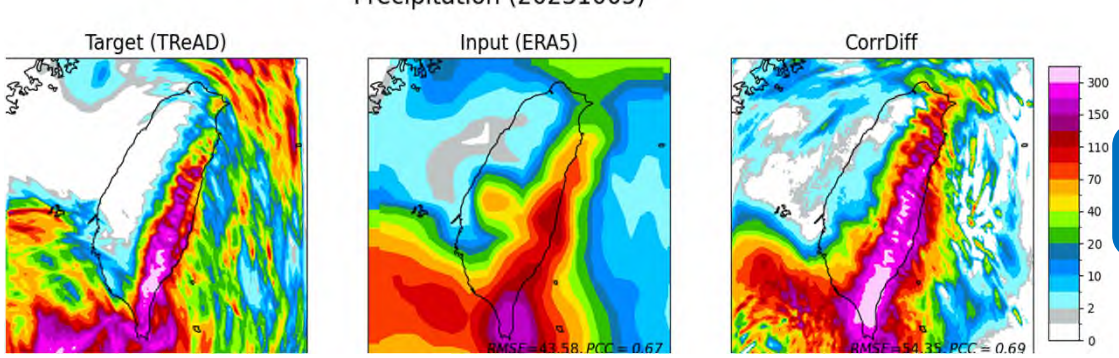


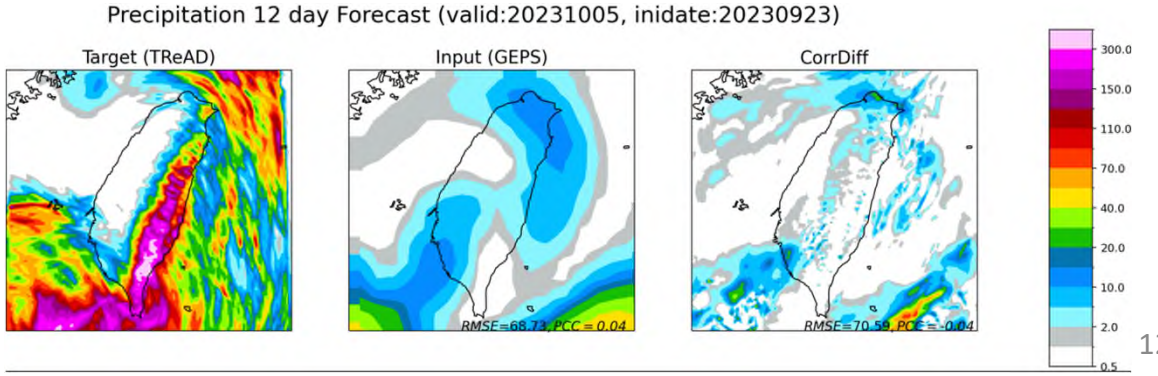
Lead 8-Day



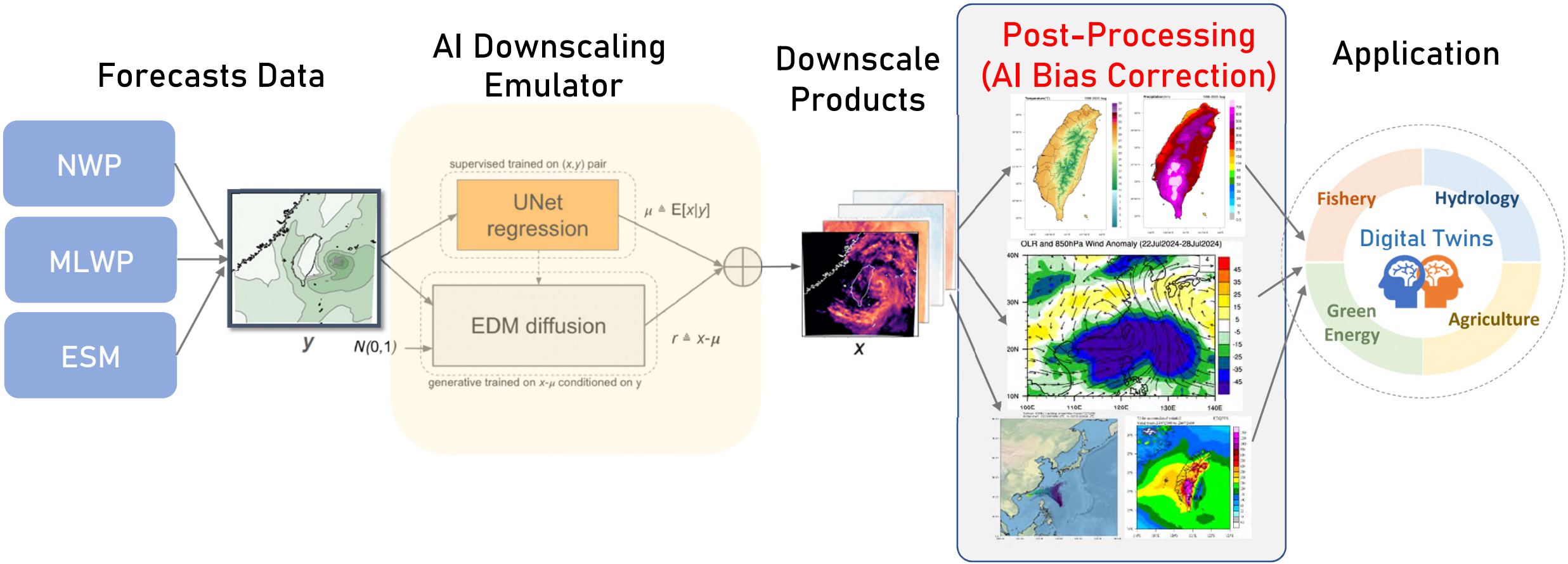
TReAD **ERA5** **SF2P**

Lead 12-Day





CorrDiff and Post-Processing



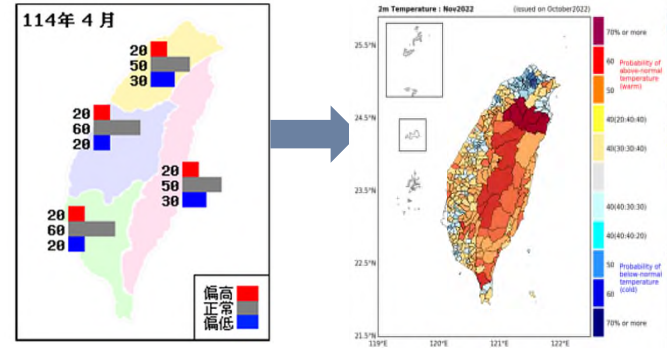
- Develop an AI downscaling simulator to 2-kilometer resolution downscaling simulations for Taiwan using global model forecast data (NWP, DWP, ESM). With bias correction techniques, this simulator will produce forecast products with reduced errors, tailored for customized applications across various domains.

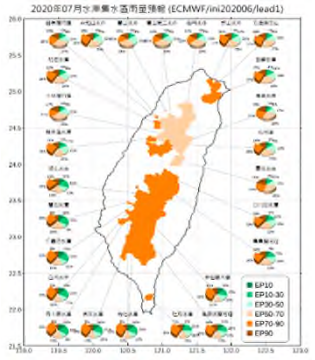
Summary and Future Work

1) The preliminary results indicate that CorrDiff model provides good downscaling performance, but further research is needed to better understand and improve CorrDiff. CWA need to collaborate with University and NVIDIA to jointly develop an AI downscaling simulator.

2) Application of CorrDiff in CWA:

- Supporting CWA's monthly and seasonal climate forecasts, with spatial resolution **from 4 regional to Township scale**.
- **Cross-Sector applications**, such as in water resources, agriculture, fisheries, and green energy.
- CWA plans to develop **interannual and decadal forecasts** in the future, with CorrDiff model playing an important role in downscaling.





Seamless Forecast Product at CWA

Plan
Decadal Forecasts

Support formulating government policies

Ready
Seasonal Forecasts

Begin monitoring mid-range and short-range forecasts
Enable early-warning system

Set
Mid-Range Forecasts

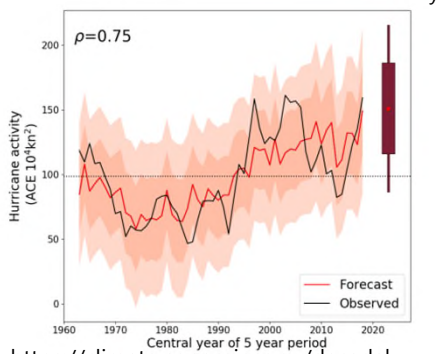
Alert volunteers
Warn community
Local preparation activities

Go
Short-Range Forecasts

Deploy assessment team
Activate volunteers

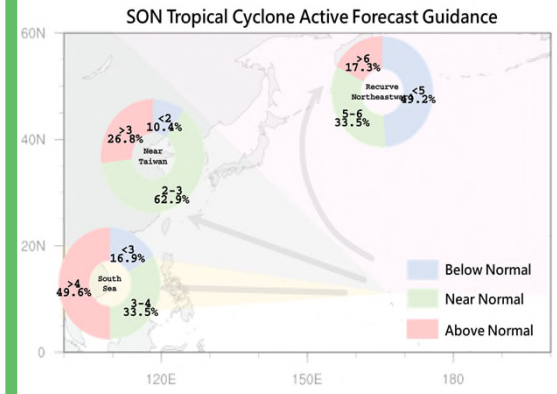
TC Decadal forecasts

Historical and forecast hurricane activity



https://climate.copernicus.eu/decadal-predictions-insurance

TC seasonal forecasts



TC Week 1-4 Forecast

TC Warning

Thanks for your listening!