Technical Presentations

AI based TC real-time analysis system in KMA

Woojeong Lee, Seonghee Won, Hyun-soo Lee

National Typhoon Center/KMA

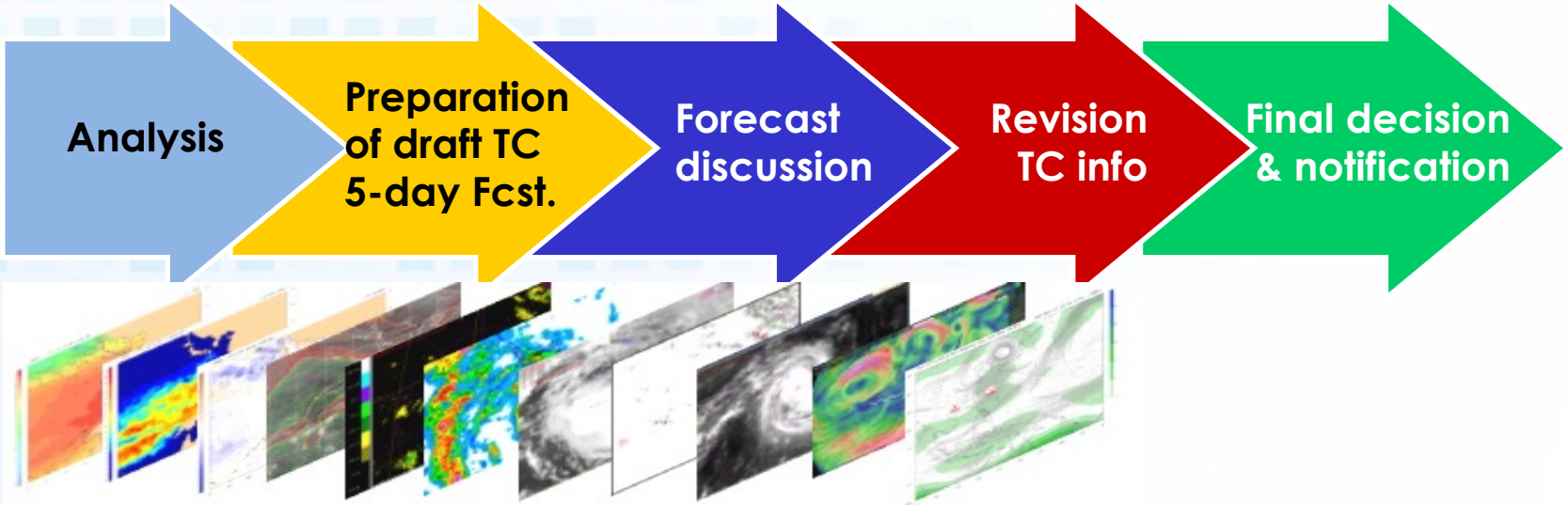
기상청
Korea Meteorological Administration

CONTENTS

1. Introduction

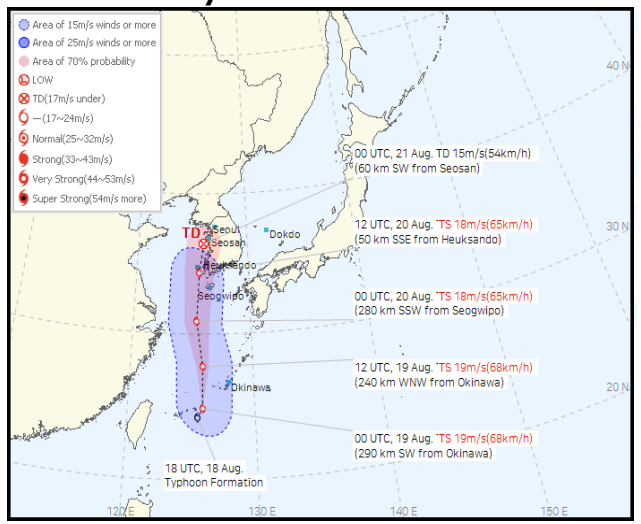
- **KMA issues an official 5-day forecast** of position, intensity and size
  for Tropical cyclones in western North Pacific
  4 times a day every 6 hours at 0000, 0600, 1200, and 1800 UTC
  for TCs which will be expected Korean Peninsula
  8 times a day every 3 hours at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC

- **Forecasters are allowed a couple of hours for preparing the first draft of the TC 5-day forecast**, considering that the needed time for multiple revisions through forecast discussion with relevant divisions and check the latest NWP and observation data.



Workflow for TC 5-day forecast production system in NTC

KMA TC 5-day Forecast and Notification



1. Introduction

- **The estimation of current TC center, intensity and size** is the **first step for the TC 5-day forecast**
- TCs develop on the warm tropical oceans, therefore, forecasters **are highly dependent on satellite data** to estimate current TC information
- Estimating the TC through satellite data analysis by each forecaster is **both time consuming** and **subjective.**

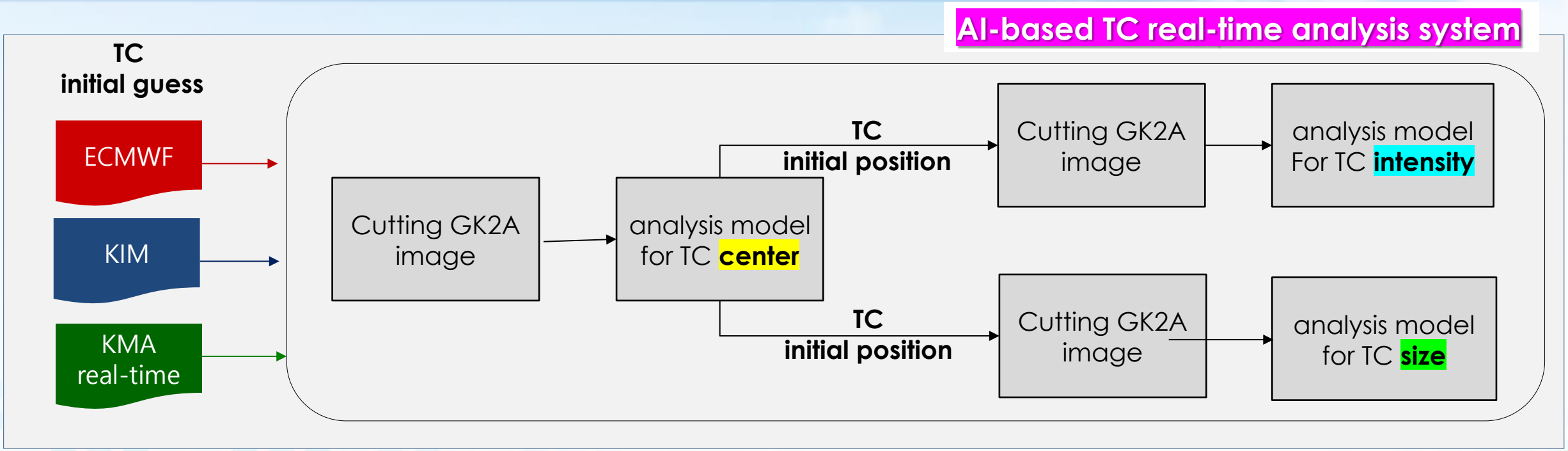
Improvement in TC analysis & forecast error in western North Pacific

Lessen the analysis time of current TC

Provide TC Forecasters with **Objective Guidance** in **real time**

Development of the **AI-based Automatic TC analysis system**

1. Introduction



- NTC developed **AI based TC center, intensity and size analysis model each.**
- Using three kinds of initial guess from ECMWF, KIM, KMA real-time analysis, the GK2A image is cut and perform the TC center analysis model. The average of estimation TC center resulting in TC center analysis model is used to TC intensity and size model as the initial position. The TC intensity and size analysis model is performed in parallel.
- Running **every 1 hour** everyday and the each result provided to forecasters **within 10 minutes**

2. Data and Method: ① Estimation of TC center

★ target variable

JTWC best track
TC center

Pre-processing

★ **TC position**,
4 random positions
following gamma distribution

Himawari-8
IR, VIS

Pre-processing

Image data cutting
centered random position
(10.4, 8.6-11.2, 10.4-12.4,
10.4-3.9, 0.64 μm)

Training: 80% of the 2016-2020

Test: 20% of the 2016-2020

daytime ?

Y

N

Input

① 0.64 + ②10.4 + ④ 10.4 8.6-11.2

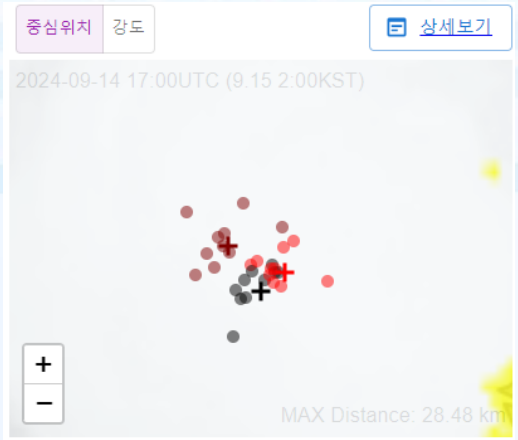
① 10.4 10.4-3.9 + ③ 10.4 10.4-12.4 + ⑤ 10.4, 10.4-12.4 8.6-11.2

Machine learning

CNN | **ConvLSTM**

10 TC center estimation model

An example of **TC positions** estimated from AI model



2. Data and Method: ② Estimation of TC intensity

★ target variable

JTWC best track
TC center

Himawari-8
IR, WV

Pre-processing

TC position,
★MWS

Training: 80% of the 2016-2021
Test: 20% of the 2016-2021

Pre-processing

Image data cutting
centered TC position
(10.4, 10.4-12.4, 10.4-6.9 μm)

Input

①10.4

②10.4
10.4-6.9

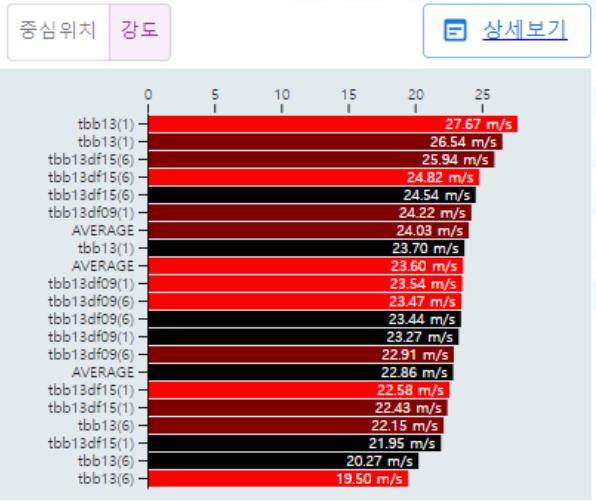
10.4
10.4-12.4

Machine learning

CNN | **ConvLSTM**

6 TC intensity estimation model

An example of **TC intensity** estimated from AI model



2. Data and Method: ③ Estimation of TC size

★ target variable

JTWC best track
TC center

Pre-processing
TC latitude, longitude

ESA and NASA's
SMOS/SMAP Wind

Himawari-8
IR, WV

Pre-processing
★ **Image data cutting**
centered JTWC TC position

Over 50 %
of data

Y

Pre-processing
Image data cutting
centered random position
(10.4, 7.3-6.2, 10.4-6.2, 7.3, 6.2 μm)

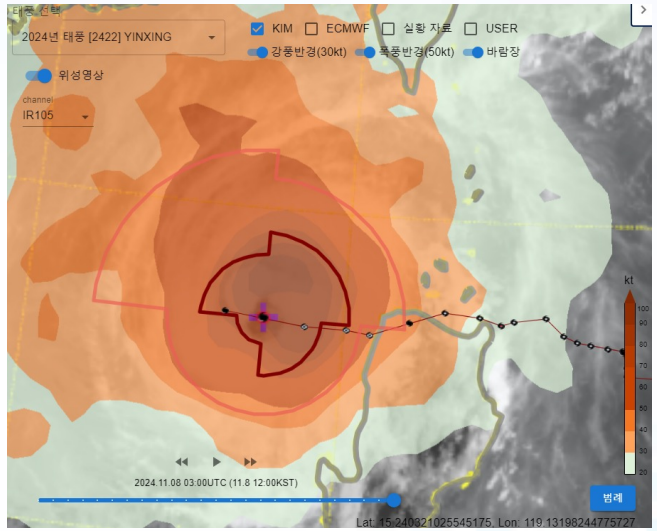
period: 2016-2023

Randomly sampling
75 % Training data
12.5 % Testing data

TC wind distribution
estimation model

Machine learning
Pix2Pix GAN

An example of **TC wind field and 34/50kt radius** estimated from AI model



2. Data and Method: AI technique

- **CNN and ConvLSTM** are used for TC center and intensity analysis model

① **CNN** (Convolutional Neural Network)

- specialized for classifying images

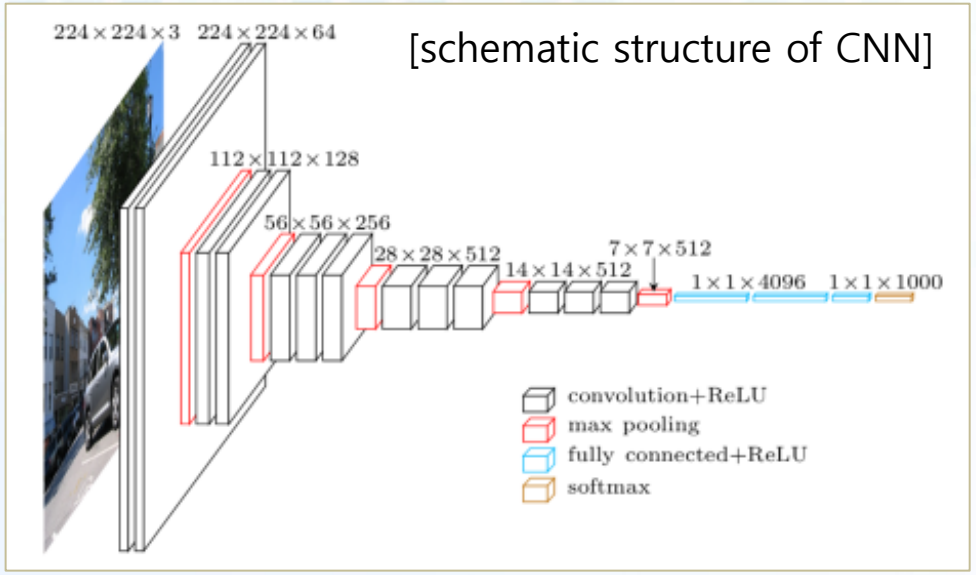
Wimmers et al. (2019), Chen et al. (2019), Higa et al. (2019), Zhou and Tan (2021)

① **ConvLSTM** (Convolutional Long Short-Term Memory)

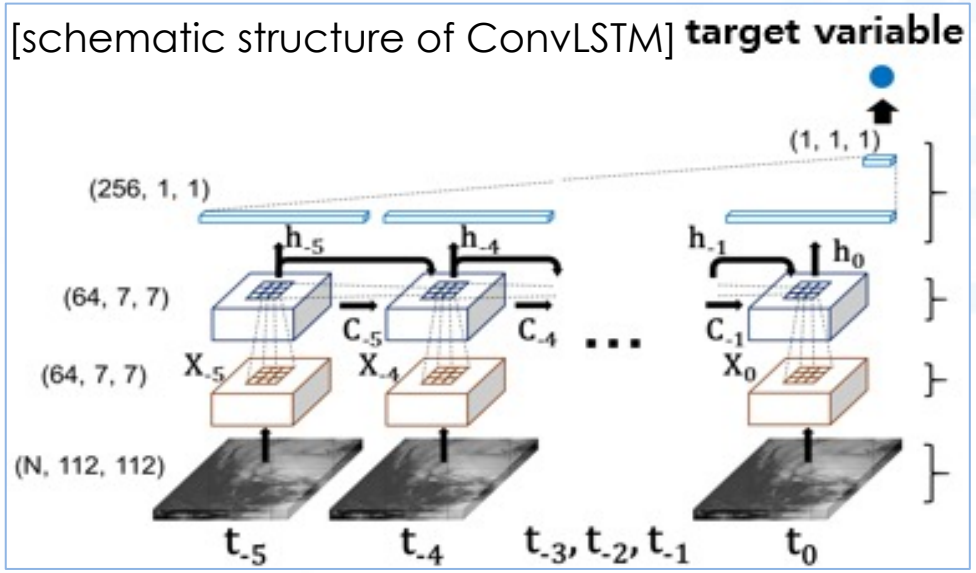
- capable of learning the temporal and spatial data
- based on Long short-term memory for handling timeseries

Smith and Toumi (2021), Dong et al. (2022)

[schematic structure of CNN]



[schematic structure of ConvLSTM]



2. Data and Method: AI technique

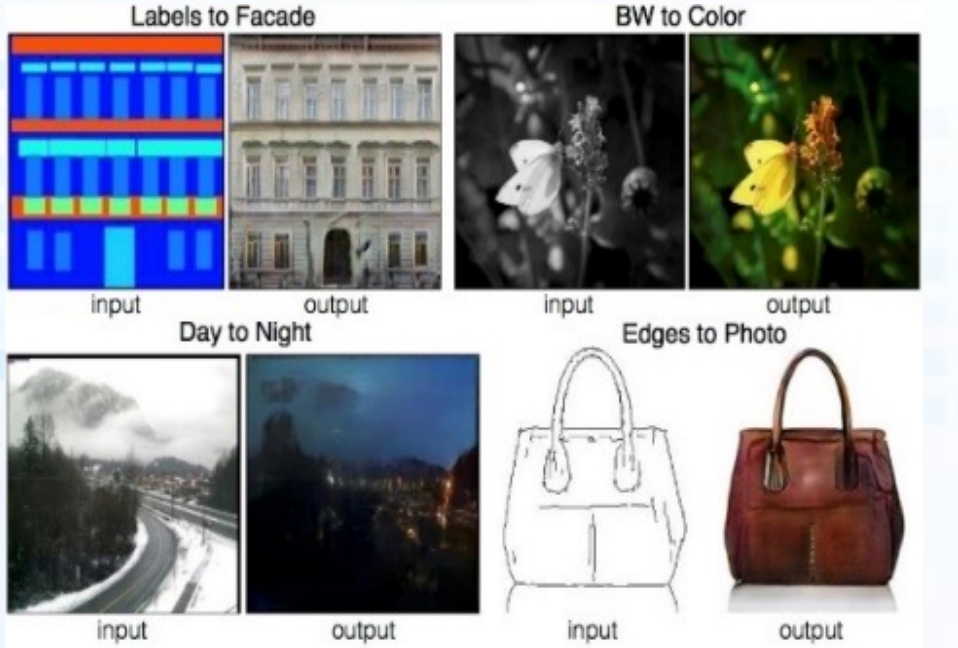
- **Pix2pix GAN** is used for **TC size analysis model**

  - specialized for converting images from one domain to another

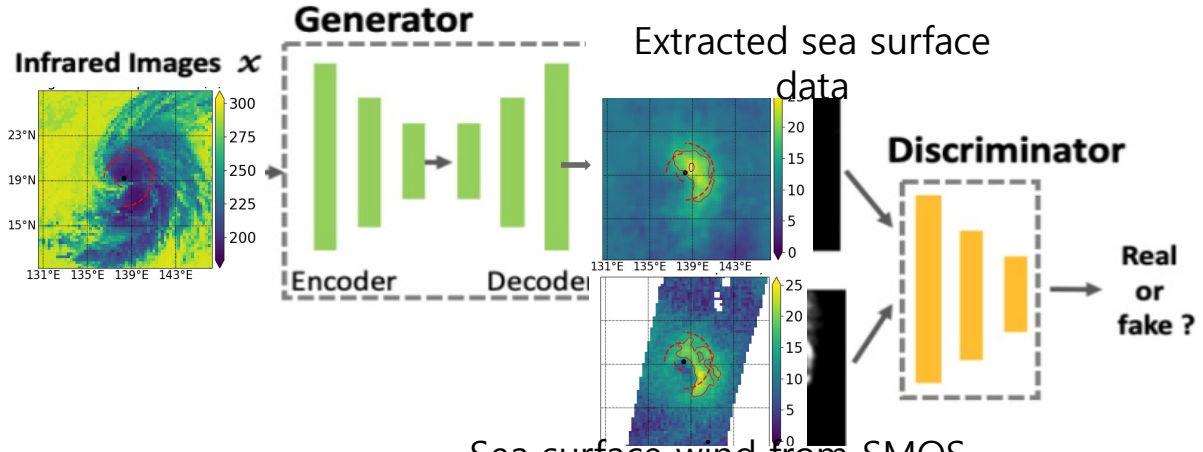
  - The **generator** and **discriminator** are trained together in a competitive process. The generator aims to produce images that are indistinguishable from real images, while the discriminator learns to tell real from fake.

  - utilized for transformation between TC infrared image and microwave image (Meng et al. 2022)

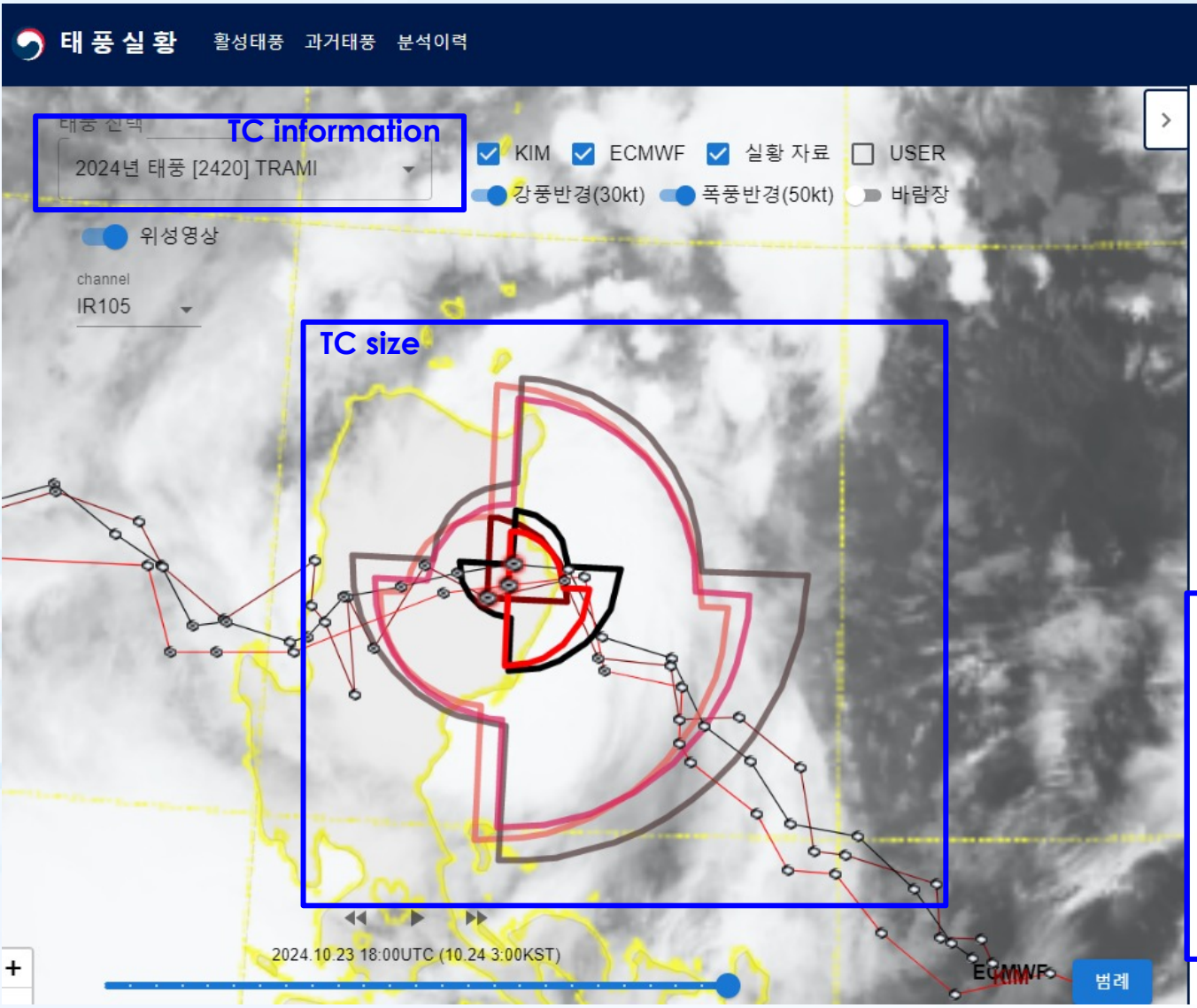
<examples of transformation between images>

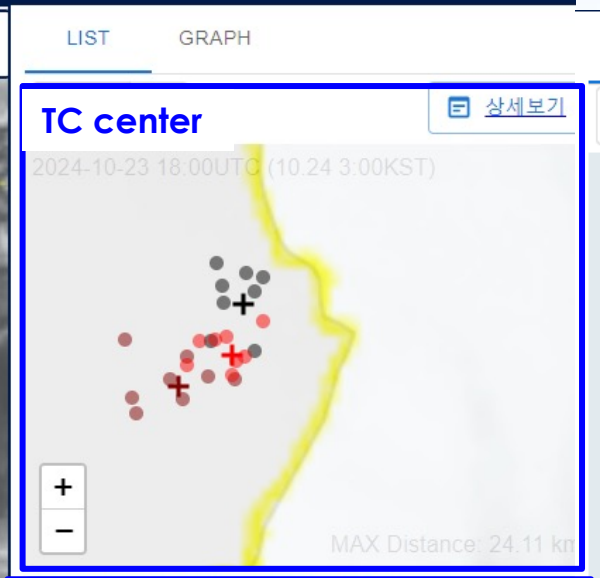


Schematic diagram of pix2pix GAN for estimation the TC wind fields

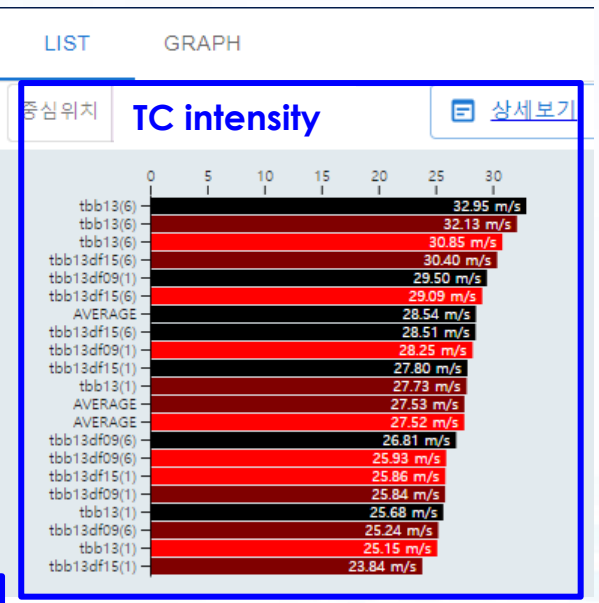


3. Result: AI based TC real-time analysis system





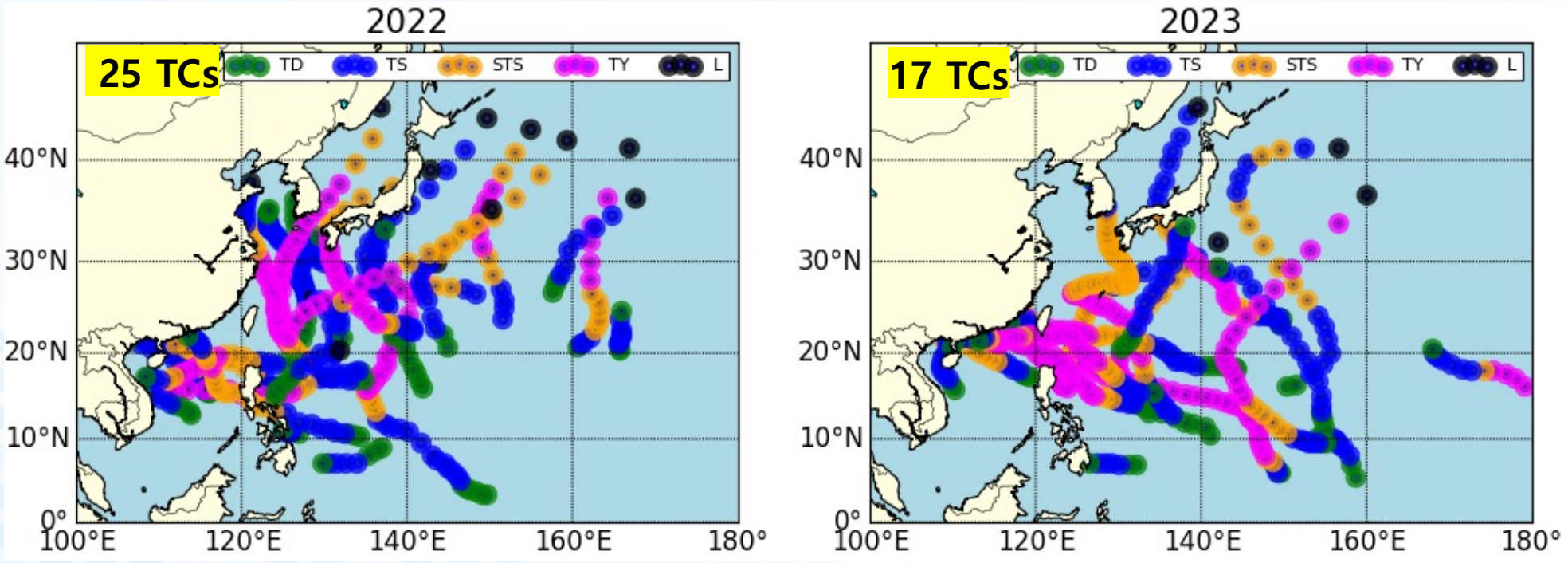
2024-10-23 18:00UTC (10.24 3:00KST)	
중심 위치 (ECMWF)	17.22° N, 122.08° E
강풍반경(30kt)	75(NW), 175(NE), 150(SW), 275(SE)
폭풍반경(50kt)	- (NW), 50(NE), 50(SW), 100(SE)
강도	28.54(m/s)
중심 위치 (KIM)	16.93° N, 121.87° E
강풍반경(30kt)	75(NW), 200(NE), 100(SW), 225(SE)
폭풍반경(50kt)	- (NW), 75(NE), - (SW), - (SE)
강도	27.53(m/s)
중심 위치 (실황 자료)	17.04° N, 122.05° E
강풍반경(30kt)	75(NW), 175(NE), 125(SW), 225(SE)
폭풍반경(50kt)	- (NW), 50(NE), - (SW), 75(SE)
강도	27.52(m/s)
2024-10-23 15:00UTC (10.24 0:00KST)	
중심 위치 (ECMWF)	17.19° N, 122.57° E
강풍반경(30kt)	100(NW), 250(NE), 200(SW), 275(SE)
폭풍반경(50kt)	25(NW), 100(NE), 75(SW), 125(SE)



Text information on the average of TC center, intensity, size by AI model

3. Results

- **TC center, intensity (MWS)** estimated from AI based TC real-time analysis system for 2022 and 2023 are **compared with KMA best track according to TC categories, TD, TS, STS and TY**

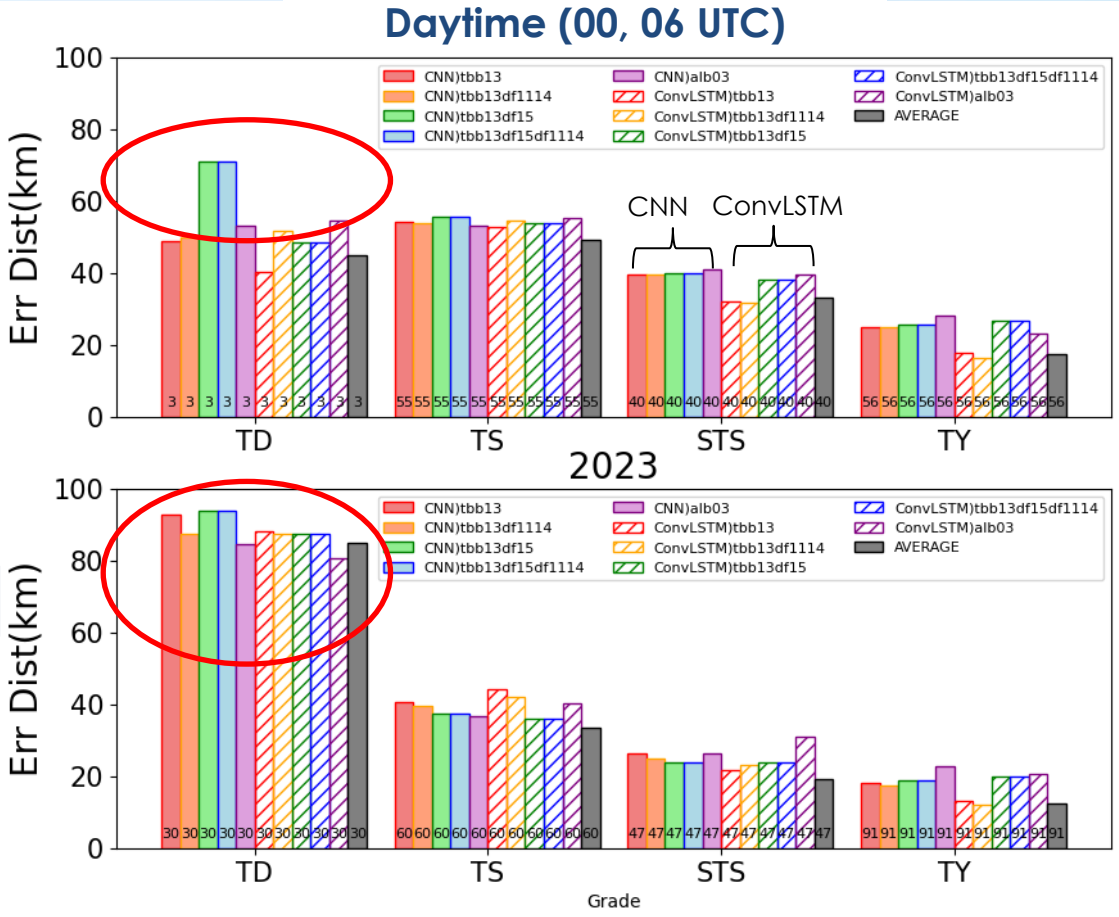


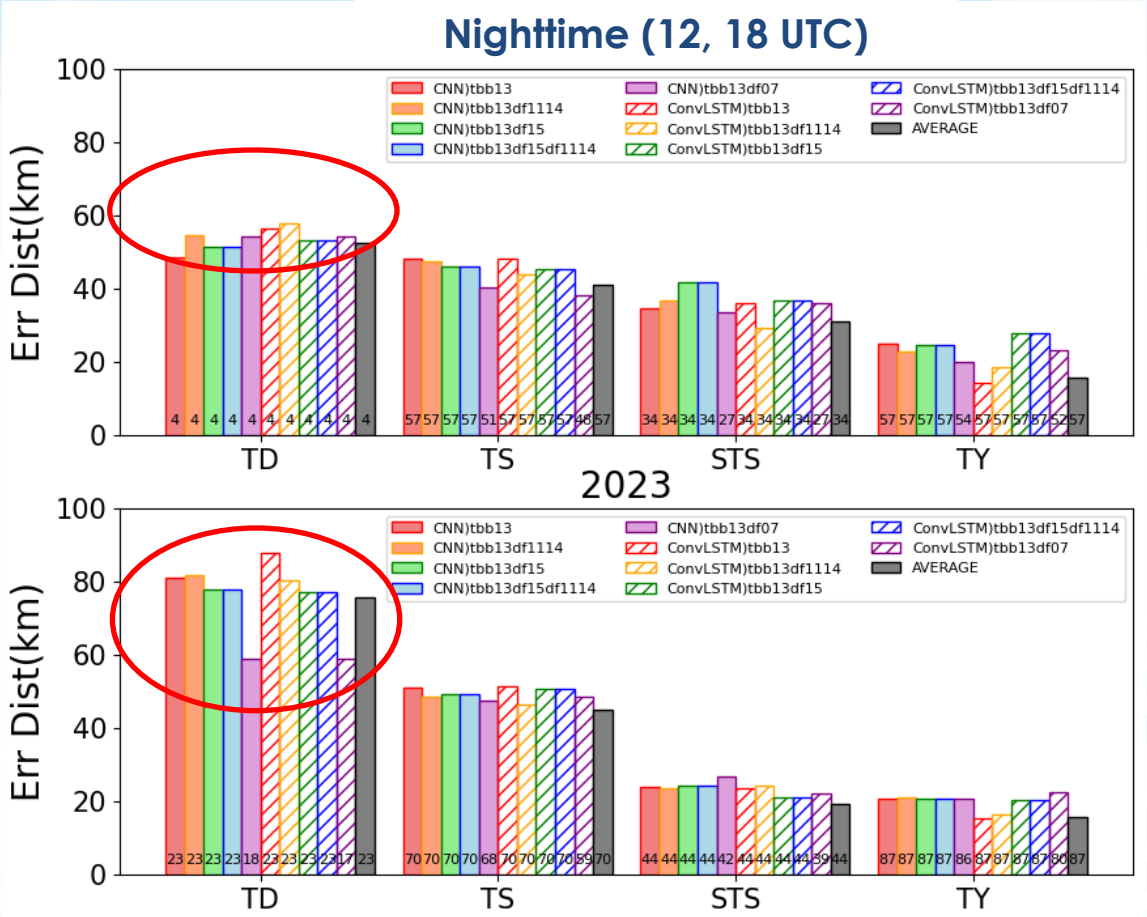
- **TC size** estimated from AI based TC real-time analysis system are **compared with SMOS/SMAP** for 12.5 % of the period from 2016 to 2023, which is not included in training and test

3. Result: TC center

2022

2023

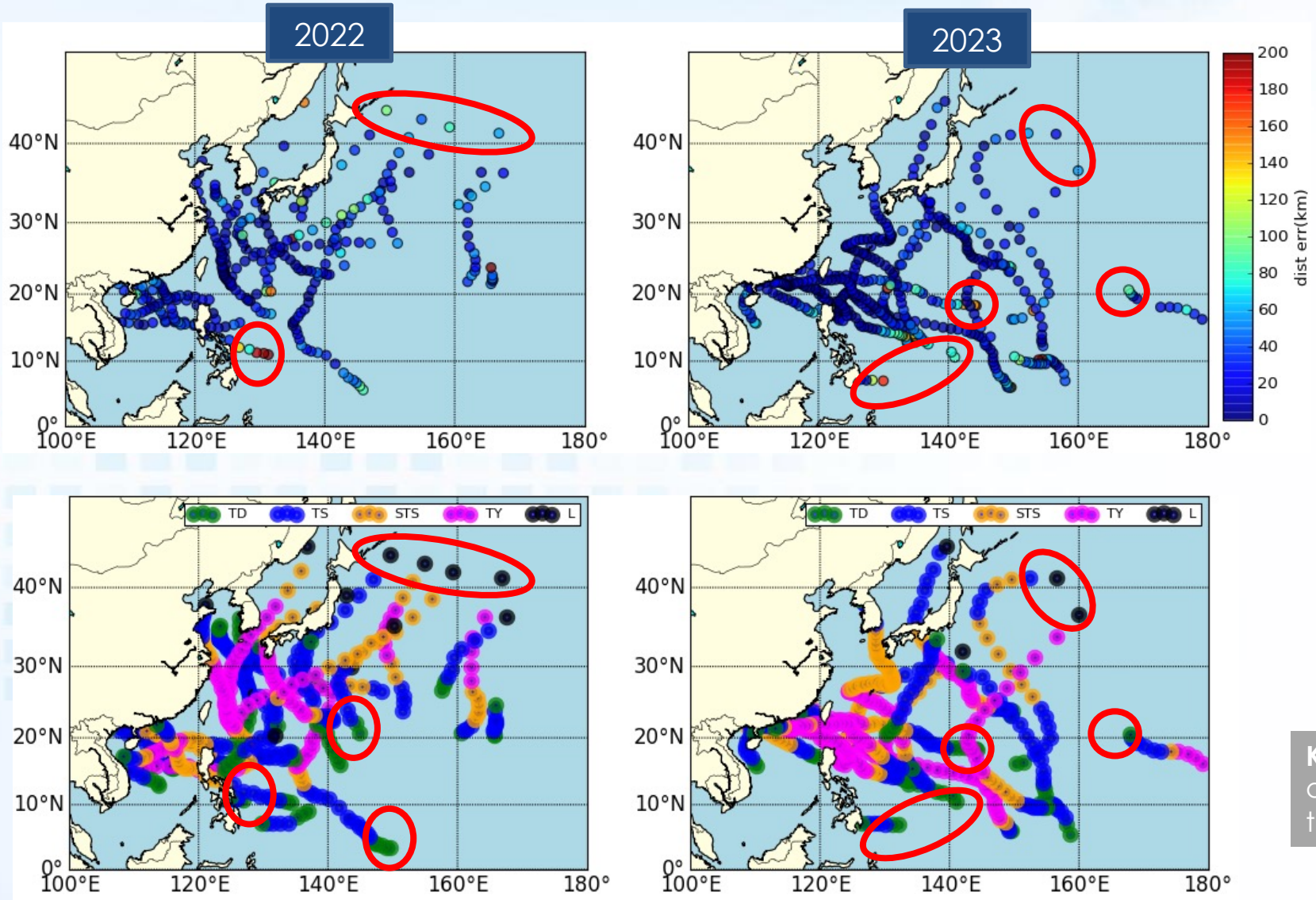




- **Mean distance error** of AI model with different the TC categories, TD, TS, STS and TY.
- There is **no significant difference** between machine learning techniques
- The stronger TCs, the smaller error becomes in the results of the both day and nighttime
- The **error** of TC center estimation except for TD are **within ~55 km**.

3. Result: TC center

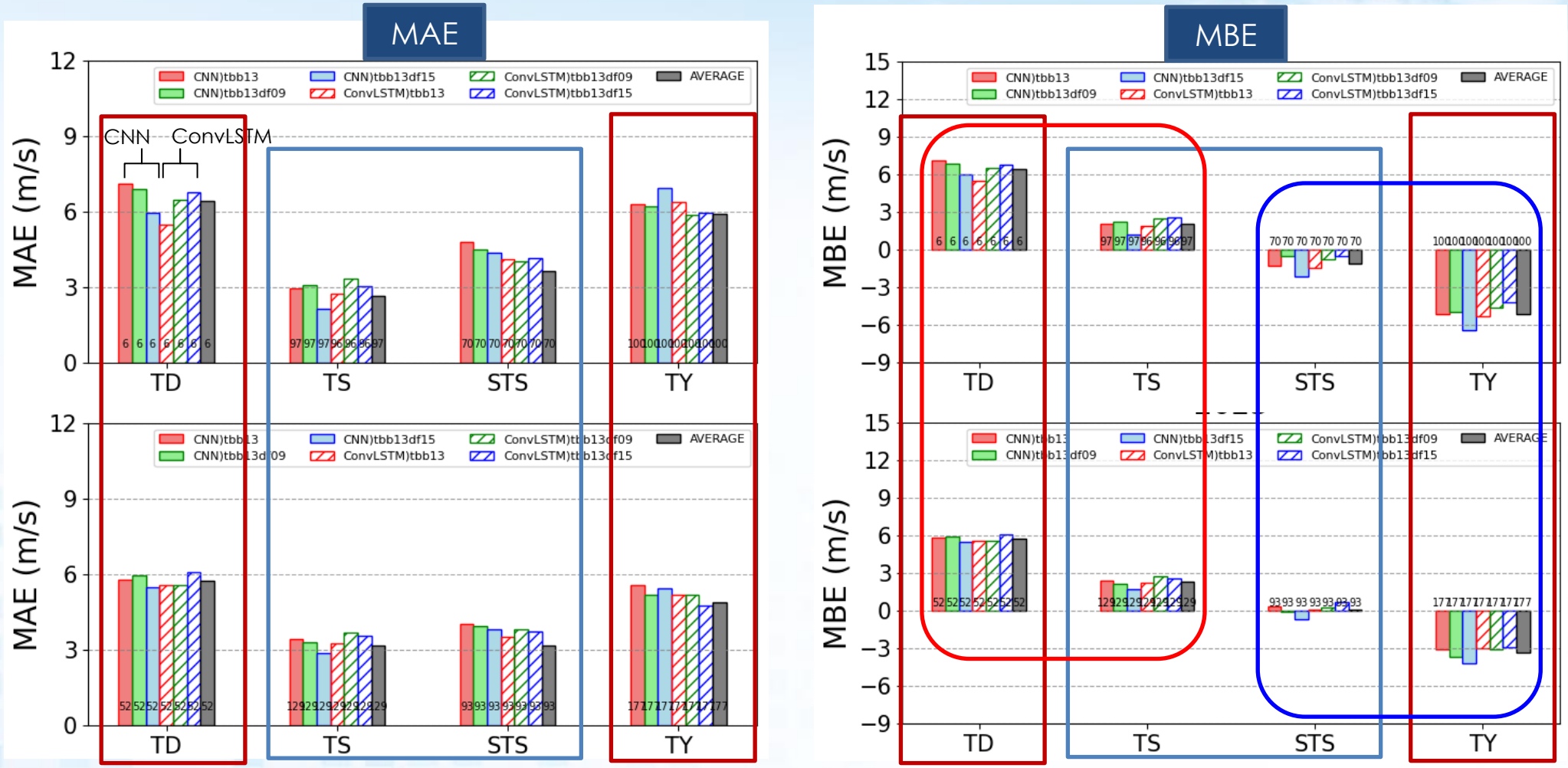
- **Comparison of TC center error distance (km) btw the AI model and best track in 2022 and 2023**



- **Most of TC position errors** are **within error of the 55 km** (blue circles) corresponding JMA's position confidence "position good" (WMO, 2024)
- Relatively **large errors** when TCs are developing (**TD**) or turning into an extratropical cyclone

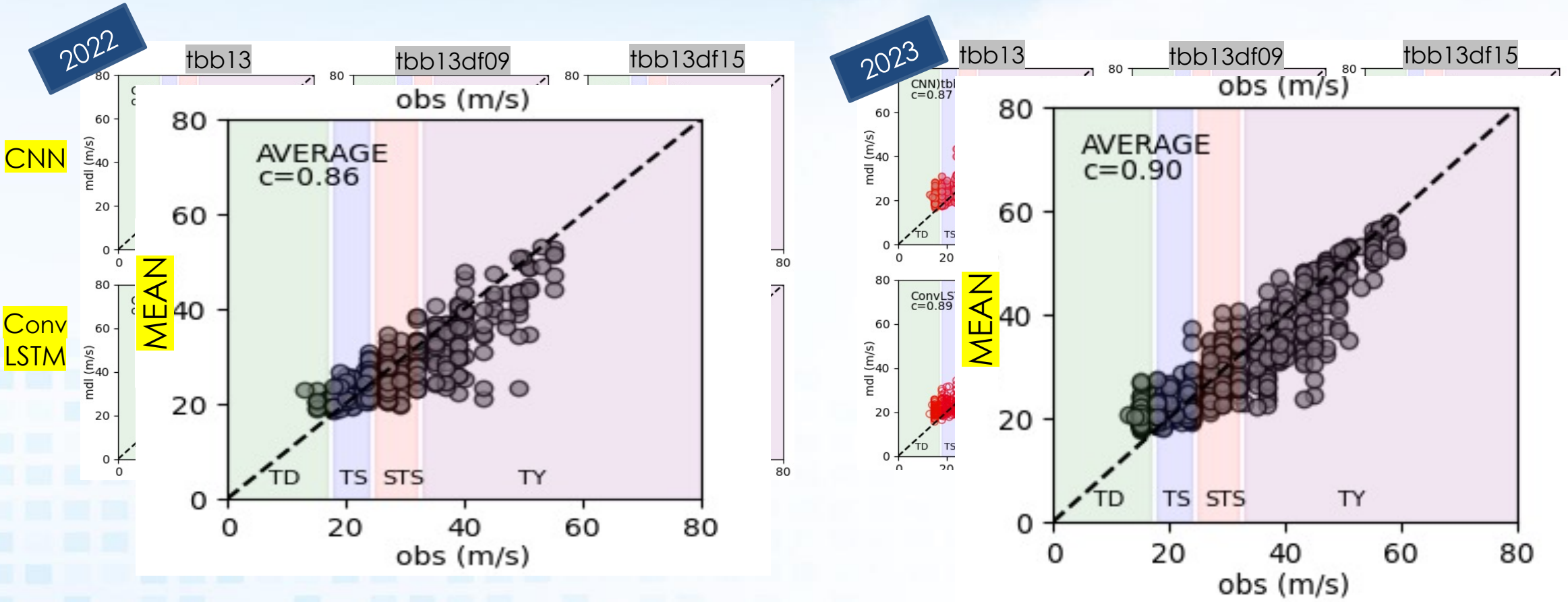
KMA TC best track positions at 6-h intervals along with the intensity of the TD, TS, STS, TY over the WNP in **2022 and 2023**

3. Result: TC intensity (MWS)



- MWS estimation of AI model exhibit
  the **relatively low MAE and MBE for moderate TCs (TS, STS)**
  the **relatively high MAE for weak and strong TCs (TD, TY)**,
  the **positive bias for weak TCs (TD)** whereas the **negative bias** for **strong TCs (TY)**

3. Result: TC intensity (MWS)

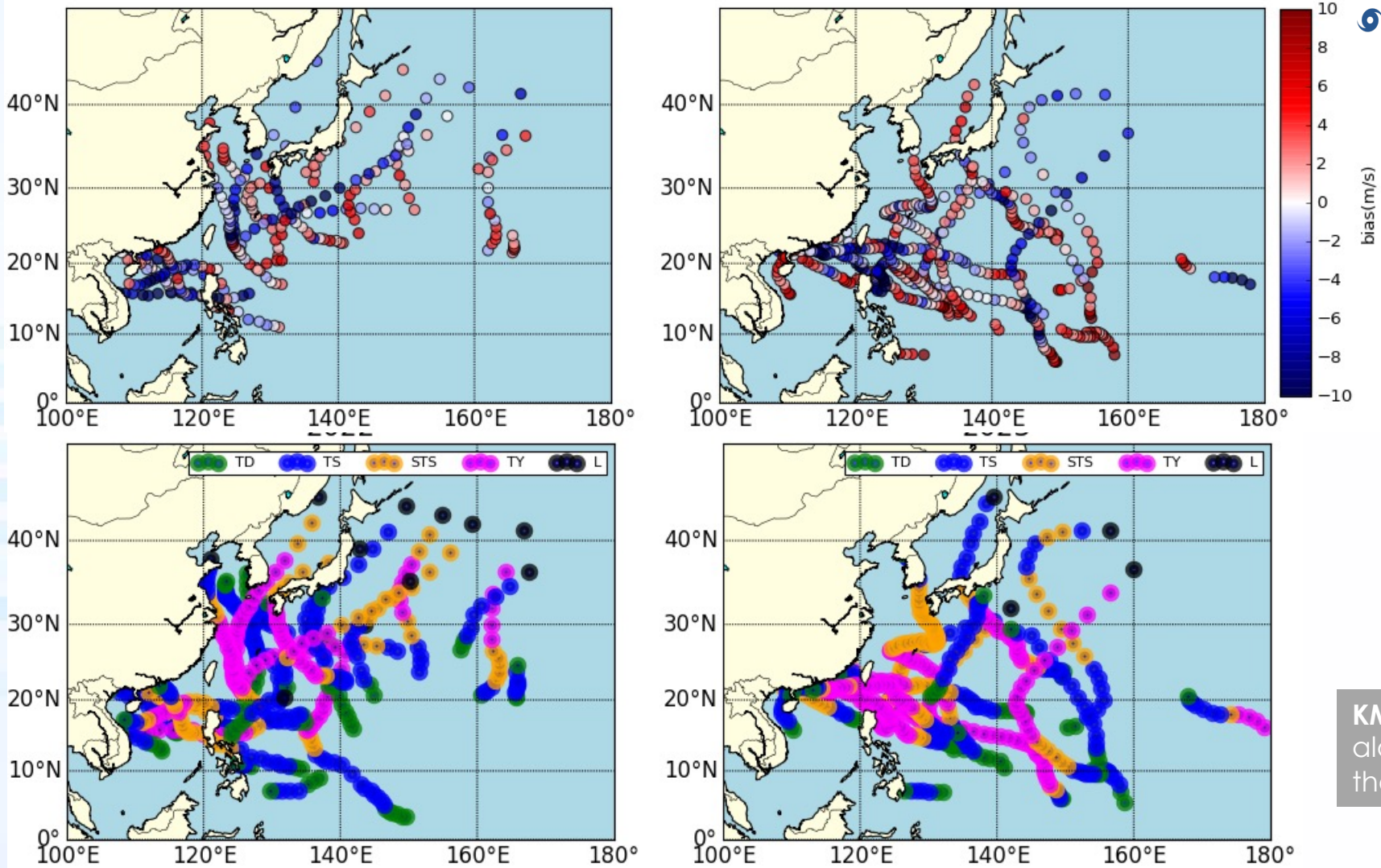


- scatter plot of each AI model and best track in 2022 and 2023
- All models tend to **underestimate** as the MWS increases.
- The average of AI model has high correlation (**0.86** in 2022, **0.90** in 2023) with observed MWS.

3. Result: TC intensity (MWS)

- Comparison of **TC intensity (m/s) bias** (modl-obs) btw the AI model and best track in 2022 and 2023

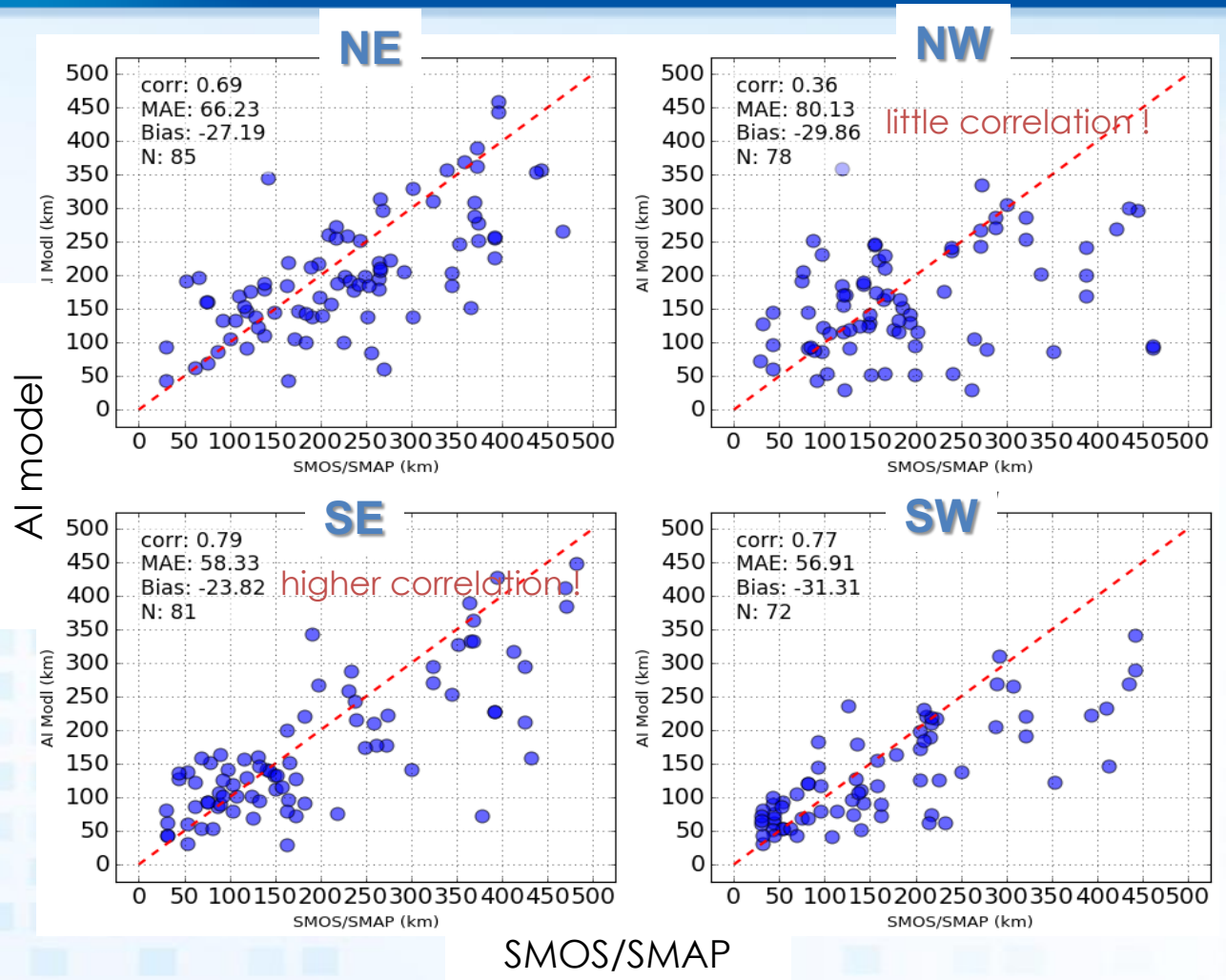
2022 2023

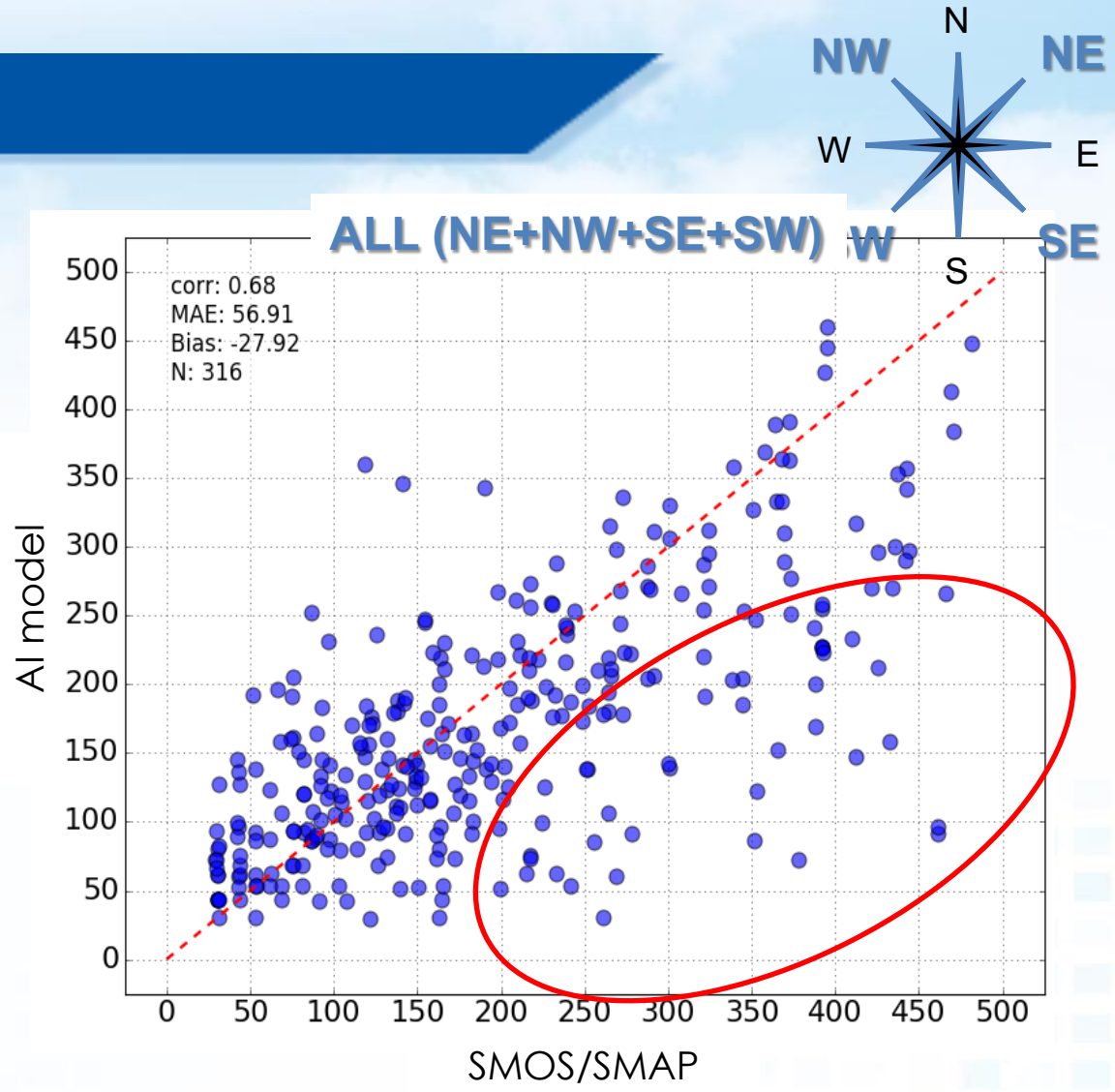


- AI show **positive** (**negative**) bias when TCs are relatively **weak** (**strong**)

KMA TC best track positions at 6-h intervals along with the intensity of the TD, TS, STS, TY over the WNP in **2022 and 2023**

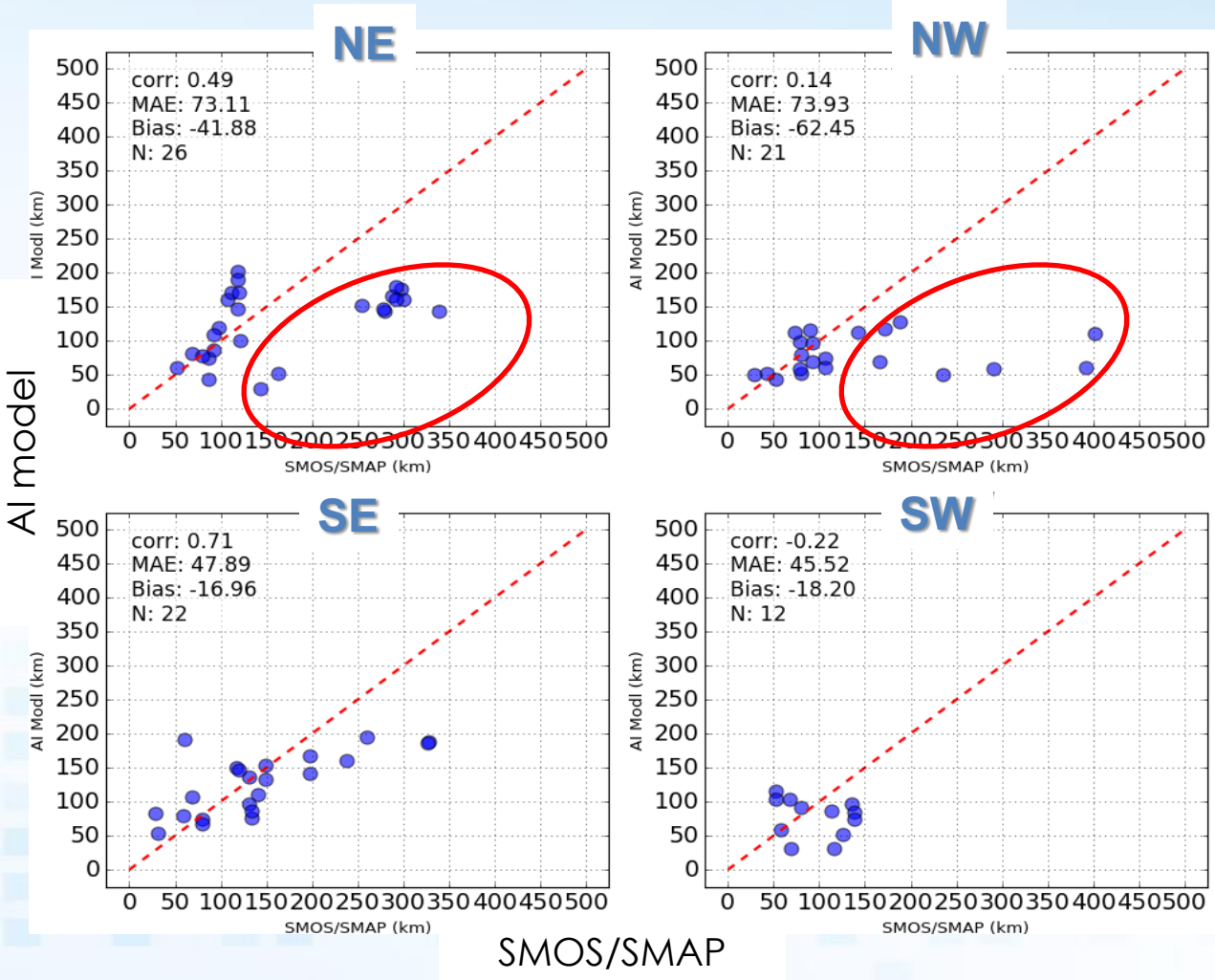
3. Result: TC size (R30)

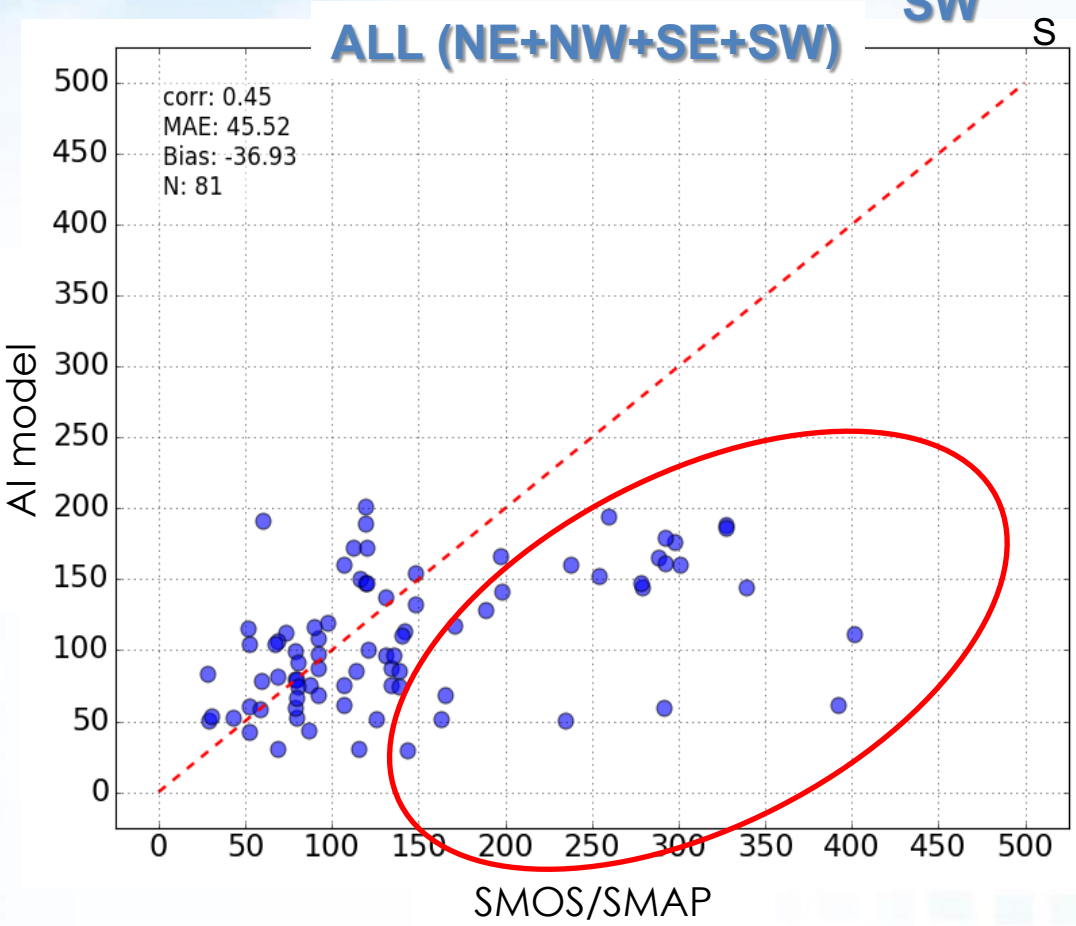


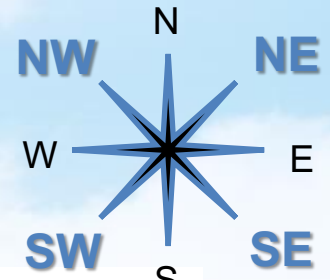


- scatter plots of **R30 (km)** estimated from SMOS/SMAP and AI model for each 4 directions
- The **correlation btw AI and SMOS/SMAP** ranges from **0.36** (NW) to **0.79** (SE)
- AI tend to **under-estimate** the R30 for all 4 directions.

3. Result: TC size (R50)

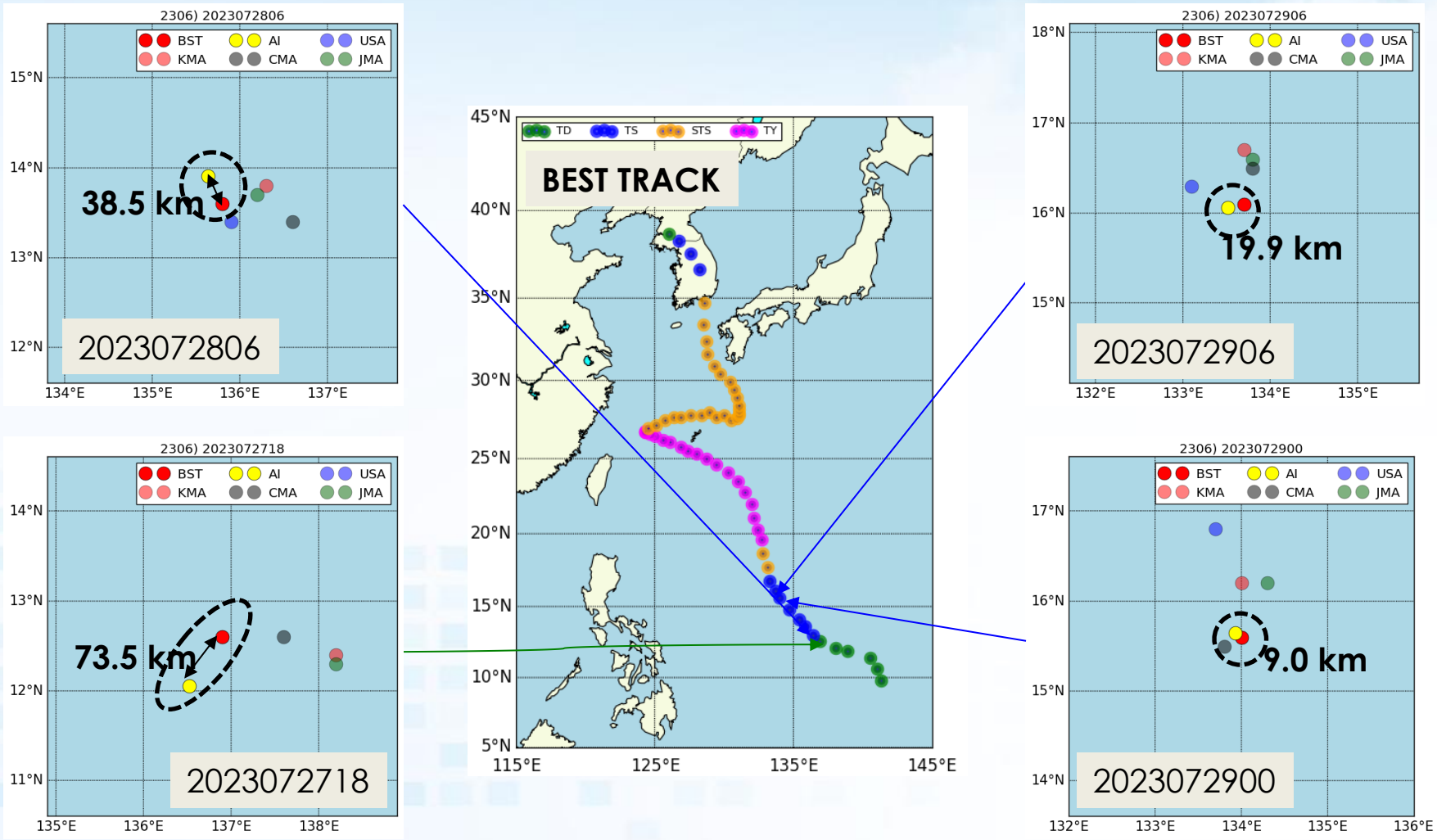






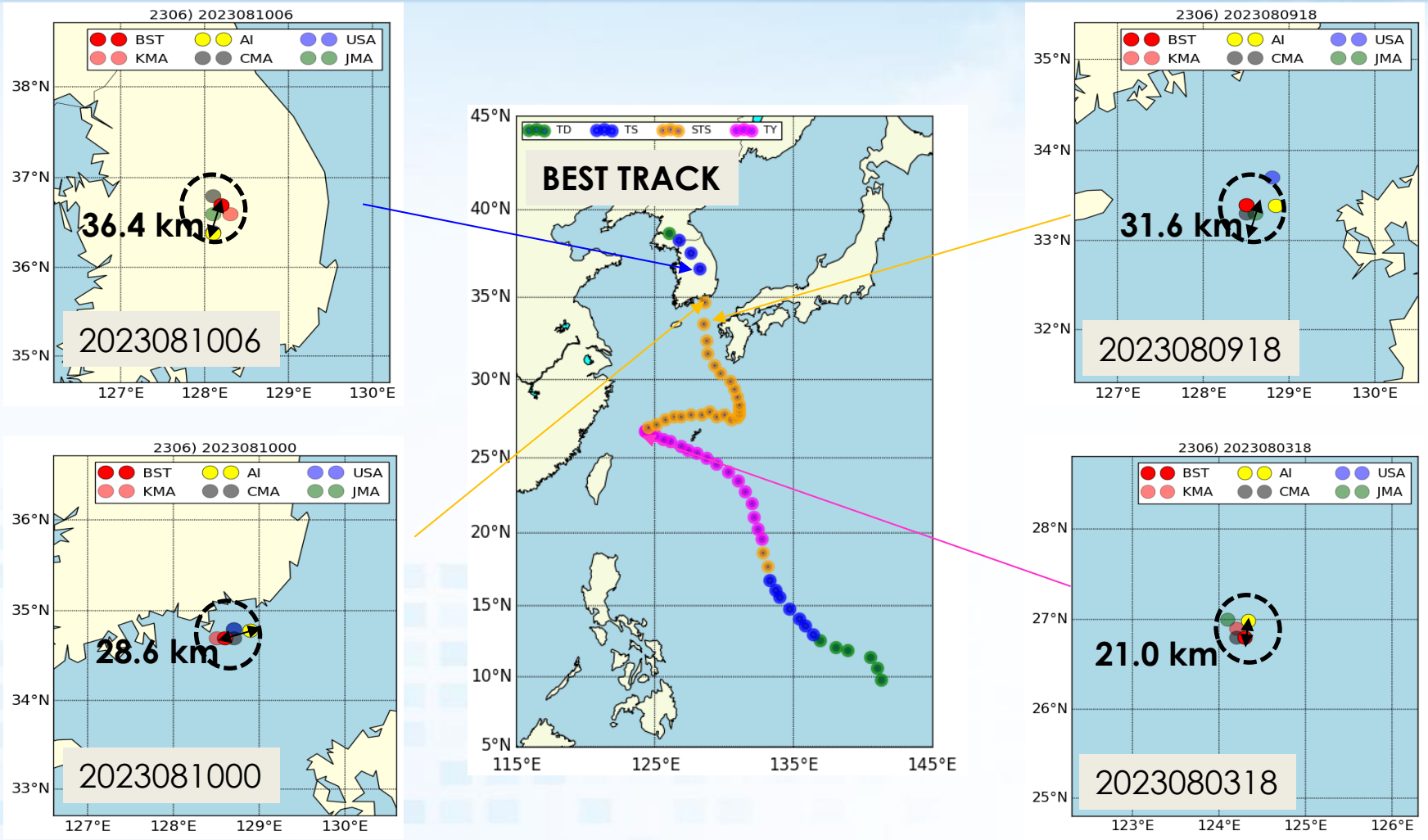
- scatter plots of **R50 (km)** estimated from SMOS/SMAP and AI model for each 4 directions
- The number of sample for R50 is very small
- The **correlation btw AI and SMOS/SMAP** for 4 directions is 0.45
- AI tend to **under-estimate** the R50 for all 4 directions

3. Result: Case study (2306 KHANUN)



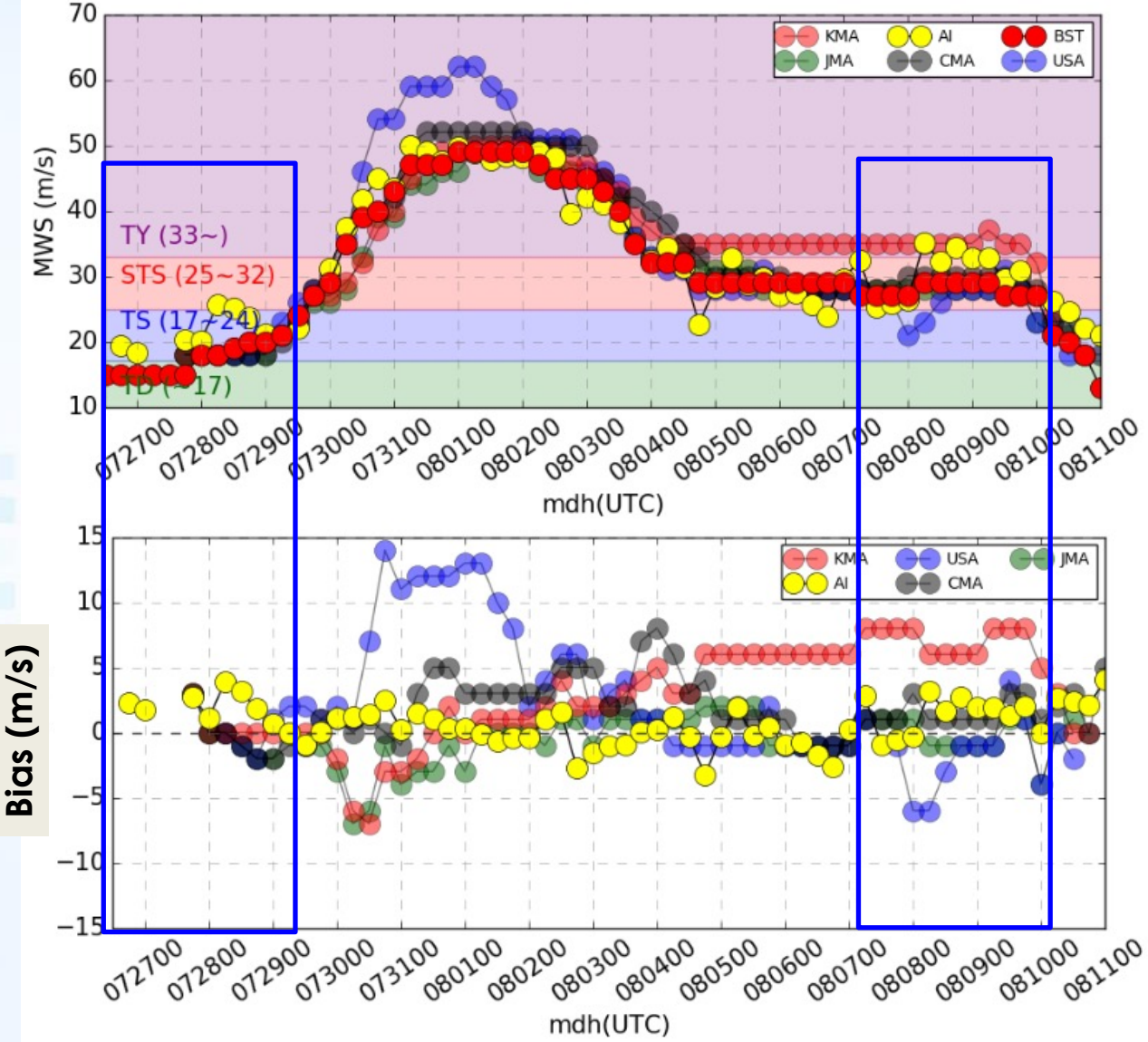
- The comparison of the position of **AI**, **KMA**, **CMA**, **JTWC**, and **JMA** real-time analysis with **best track**
- AI model gave **a <u>relatively small error in the developing stage</u>** compared with other agency's real-time analysis

3. Result: Case study (2306 KHANUN)



- The comparison of the position of **AI**, **KMA**, **CMA**, **JTWC**, and **JMA** real-time analysis with **best track**
- AI model gave **a relatively large error in the strong and weakening stage** compared with other agency's real-time analysis
- It seems that as the TCs move to high latitudes, there are a lot of material **(GTS, AWS, Radar, etc)** to use for analyze

3. Result: Case study (2306 KHANUN)



- The comparison of the intensity of **AI**, **KMA**, **CMA**, **JTWC**, and **JMA** real-time analysis with **best track**
- AI tend to **overestimate in the early and weakening stage** of TCs
- AI **overall well estimates** the tendency of the **developing and weakening** of TC KHANUN as well as Lifetime Maximum Intensity (**LMI**) compared with other agency's real-time analysis

4. Summary

- To save time needed for analysis on the current TC, we developed **AI based TC real-time analysis system** aiming to provide TC Forecasters with **objective guidance in real time**

  - each AI model for TC center, intensity and size has been developed in individual ways.

Confidence in the TC center position in JMA (WMO, 2024)
-"position good" : ~ 55 km
-"position fair" : 55 ~110 km
-"position poor": 110 km~

  - AI's real-time **estimation results for 2022 and 2023** TCs show

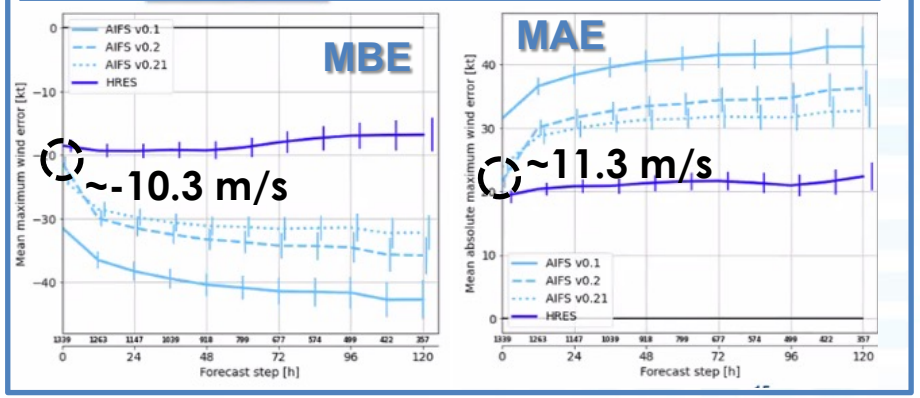
    (**center**) equivalent to "**position fair**" for **TD** and "**position good**" for **TS, STS, TY** based on the position confidence of JMA

    (**intensity**) **better estimate** compared with intensity verification of **ECMWF's AIFS**

Two-year average position and intensity errors with different TC categories between AI and best track

		TD	TS	STS	TY
position error (km) (N)		64.5 (60)	42.3 (242)	25.8 (165)	15.3 (291)
intensity (m/s)	MAE (N)	6.4 (58)	3.1 (226)	4.0 (163)	5.6 (277)
	MBE (N)	6.1 (58)	2.2 (226)	-0.5 (163)	-4.2 (277)

Intensity verification of ECMWF's AIFS
(WMO AI workshop, 2024)



  - the comparison btw SMOS/SMAP and AI model for 12.5 % of the learning period show

    (**size**) the correlations for 4 directions are **0.68** and **0.45** for each **R30** and **R50**

5. Future plan

- It is supposed to **operate the AI based TC real-time analysis system starting next year**.

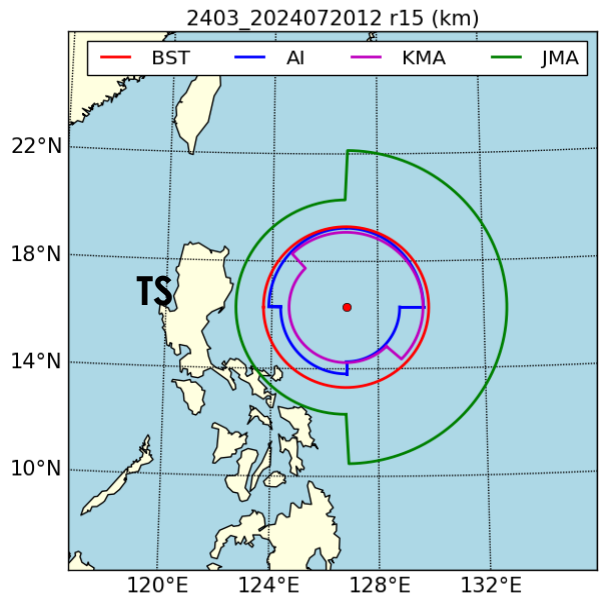
- For improvement of this system
  - need to learn more longer period or apply other advanced AI technique
  - verifications in more cases are needed to generalize the present results
  - include the interpretation of AI model's estimation results based on explainable AI technique

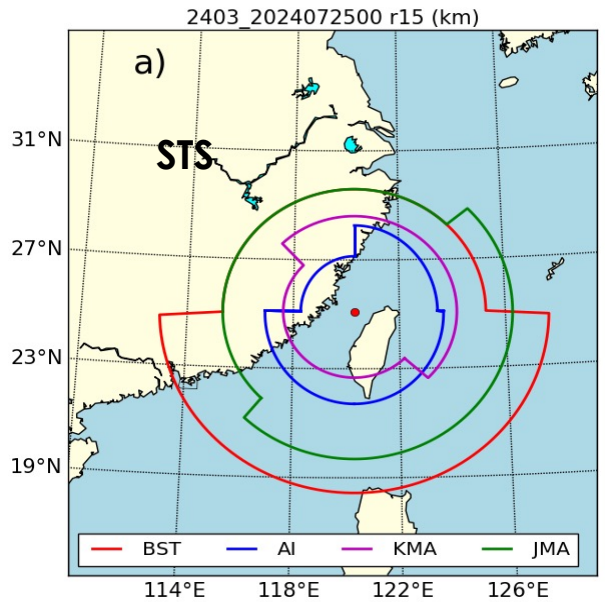
- We are planning to develop **AI based one-step integrated analysis system from TC genesis** detection to TC center, intensity and size estimation without initial **guess since next year**

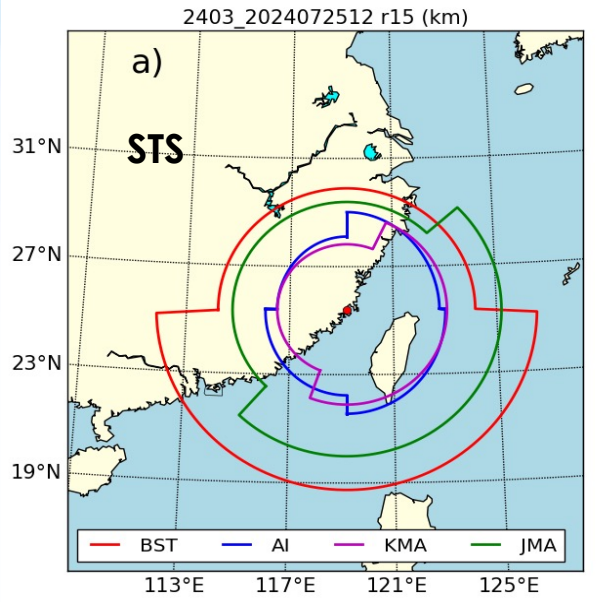
- Separately, KMA is now developing the **AI based TC prediction model** for center, intensity and size at the forecast lead time from **1 to 5 days** as well as analysis time.

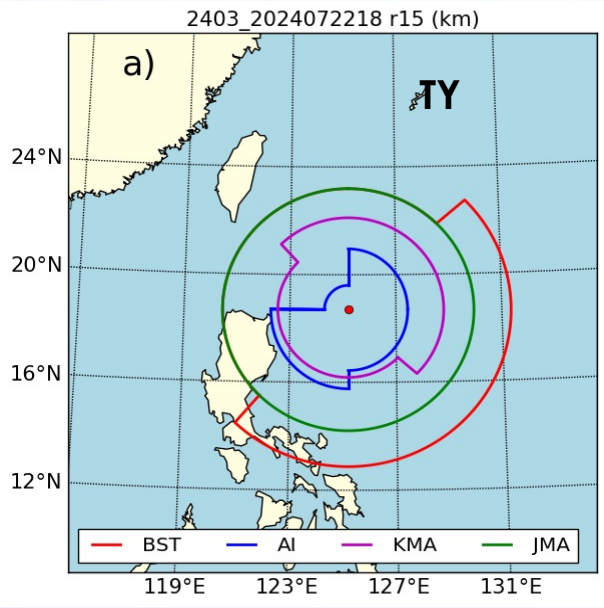
Thank you for your attention!

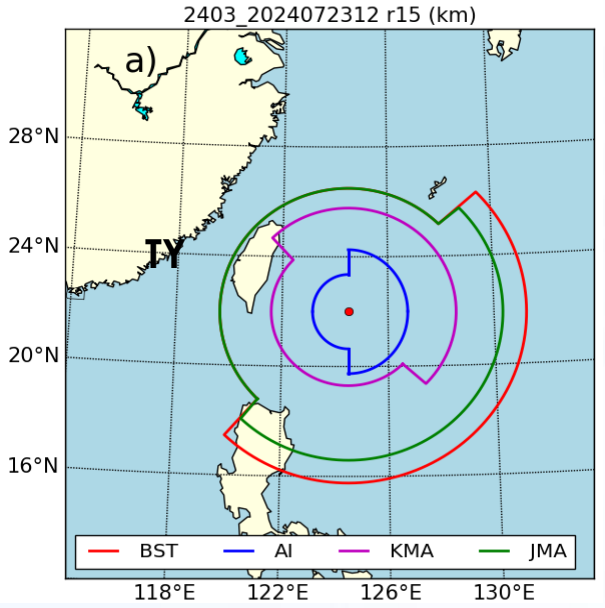
3. Result: Case study (2403 GAEMI)

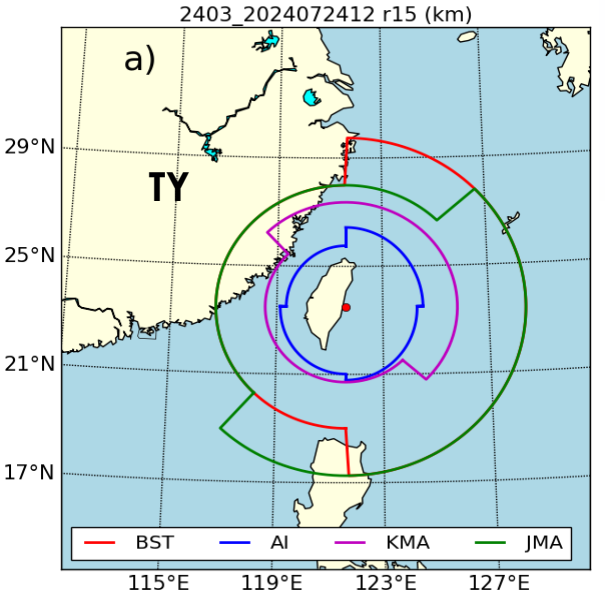












- AI estimate the radius of 30 kt well in TS
- AI estimate the radius of 30 kt relatively smaller than best track other than TS

SMOS/SMAP

	SMOS	SMAP
organization	European Space Agency (ESA)	National Aeronautics and Space Administration (NASA)
Period	2009 ~	2015 ~
Width	~1000 km	
Resolution	~40 km