105TH ANNUAL MEETING
12–16 JANUARY
NEW ORLEANS & ONLINE
AMERICAN METEOROLOGICAL SOCIETY

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13.4 WIND PREDICTION AT AIRPORT DURING TROPICAL CYCLONES USING XGBOOST MACHINE LEARNING MODEL

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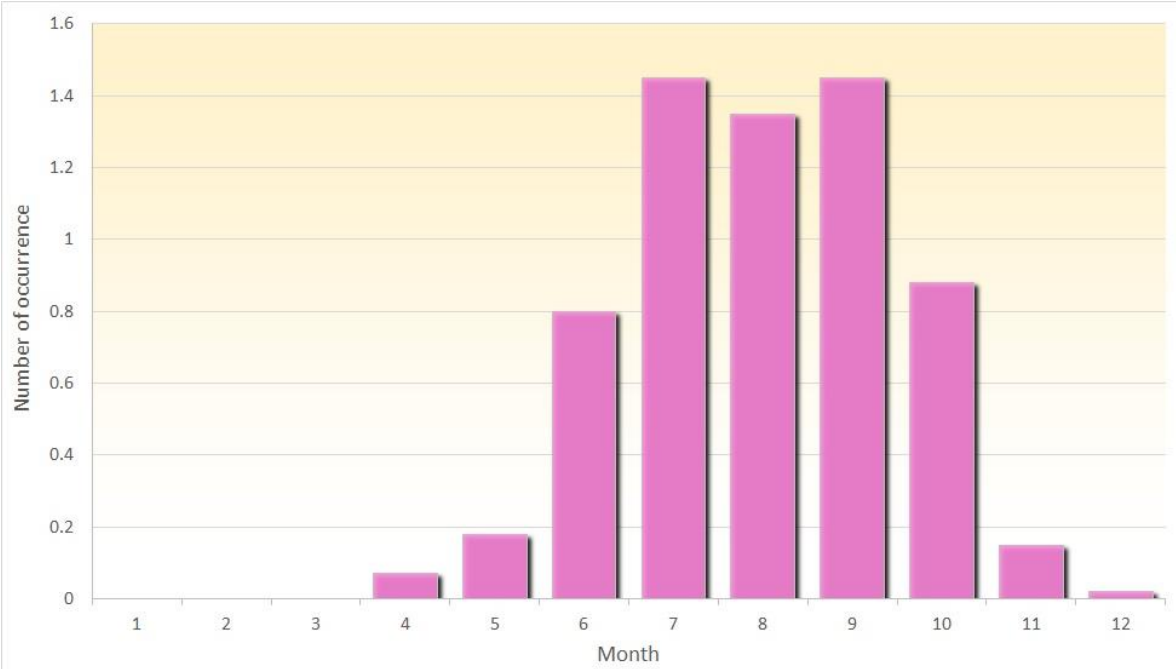
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INTRODUCTION

HONG KONG CLIMATE

- **May to November** are the months during which tropical cyclones of different intensities may strike Hong Kong
- **July to September** are the most likely months
- On average, about **30 tropical cyclones** form in the western North Pacific or China Seas every year, and about half of them reach typhoon strength (max winds of >=118 km/h).
- Heavy rain from tropical cyclones may last for a few days and **subsequent landslips and flooding** sometimes cause considerably more damage than the winds.

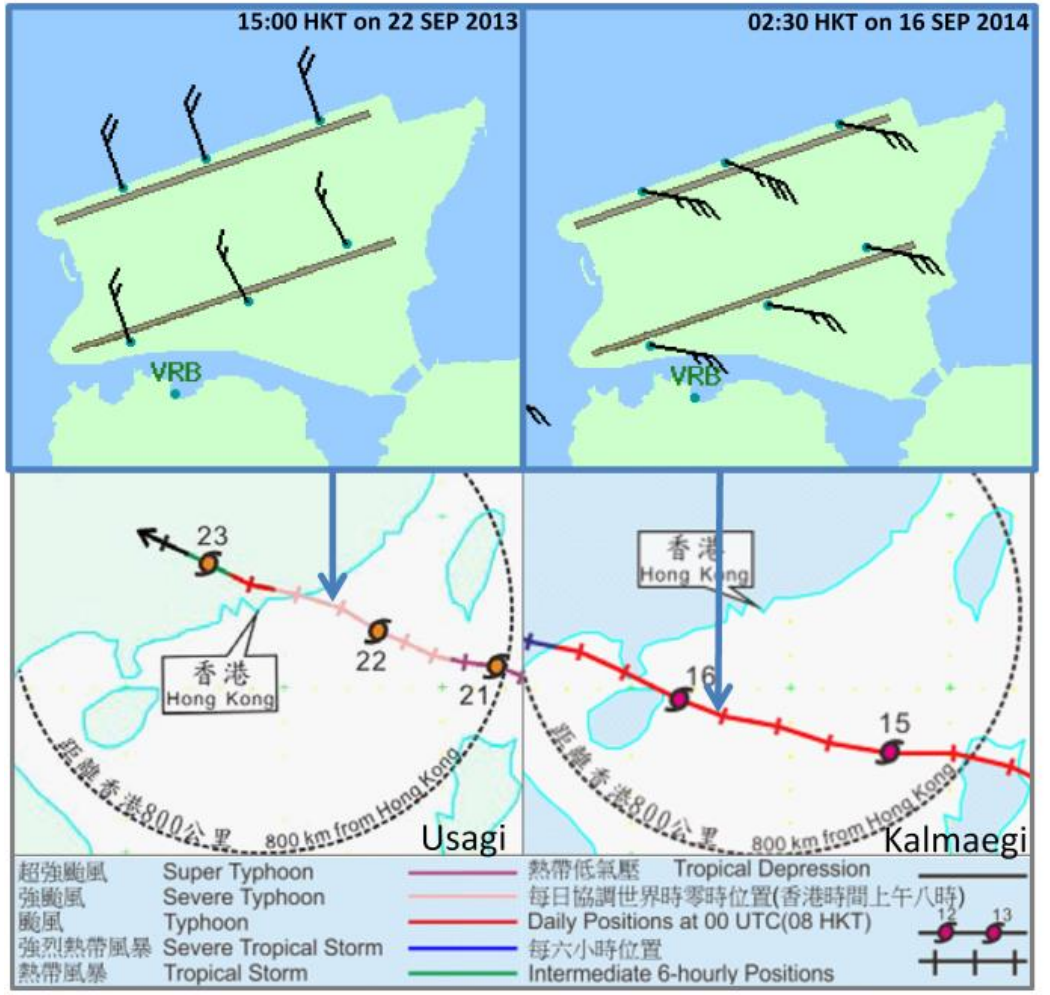


Monthly mean number of occurrence of Tropical Cyclones affecting Hong Kong (1961-2020)

INTRODUCTION

IMPACT TO THE HONG KONG INTERNATIONAL AIRPORT (HKIA)

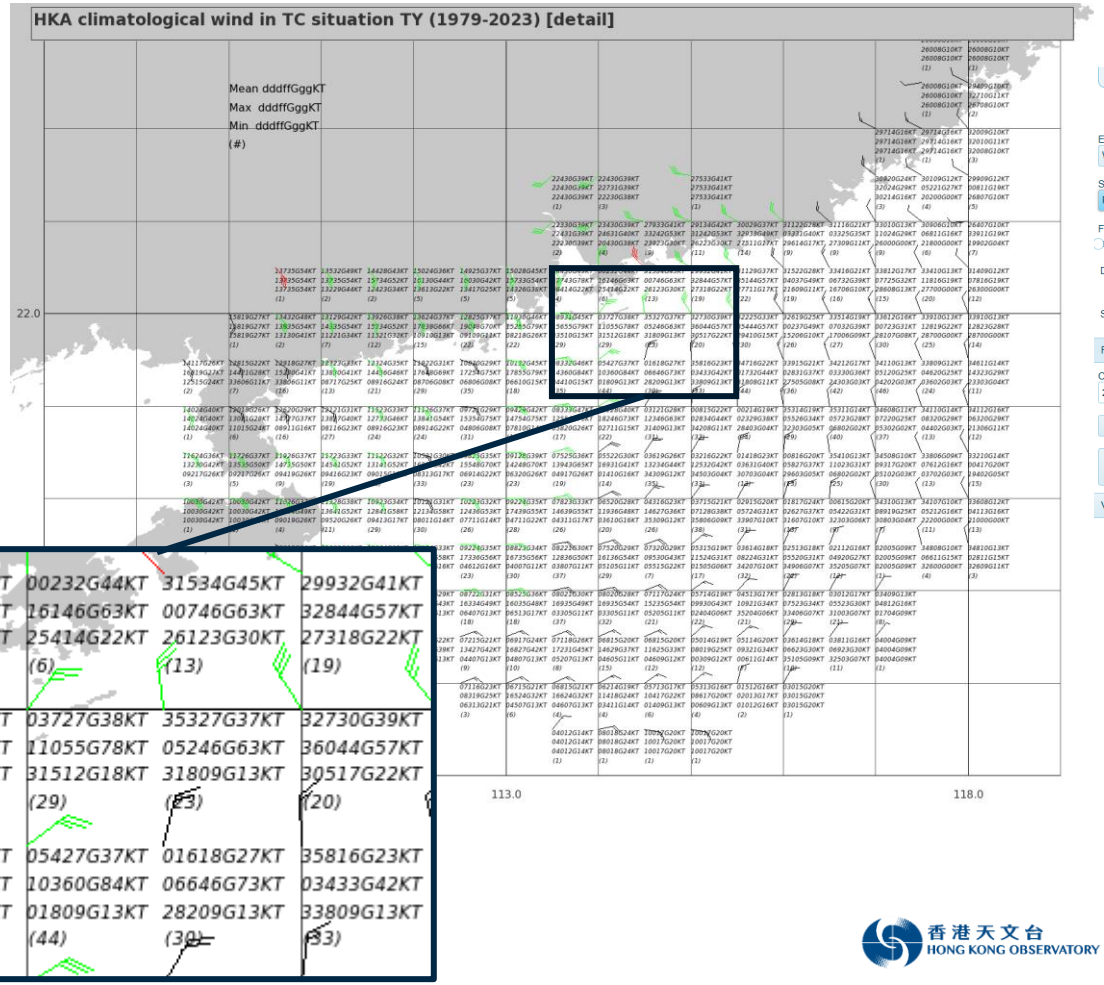
- High wind speeds, after passing through the mountain gaps, usually induce **significant windshear and turbulence**
- Aircraft may not be able to land when the **crosswinds** exceed certain limit which depends on aircraft types, loading and other factors
- Strong winds over HKIA also adversely affect **personnel working outdoors** on aircraft parked on the ground for unloading or loading and at other airport facilities.



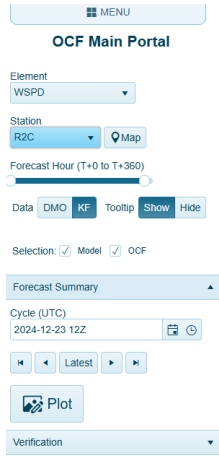
INTRODUCTION

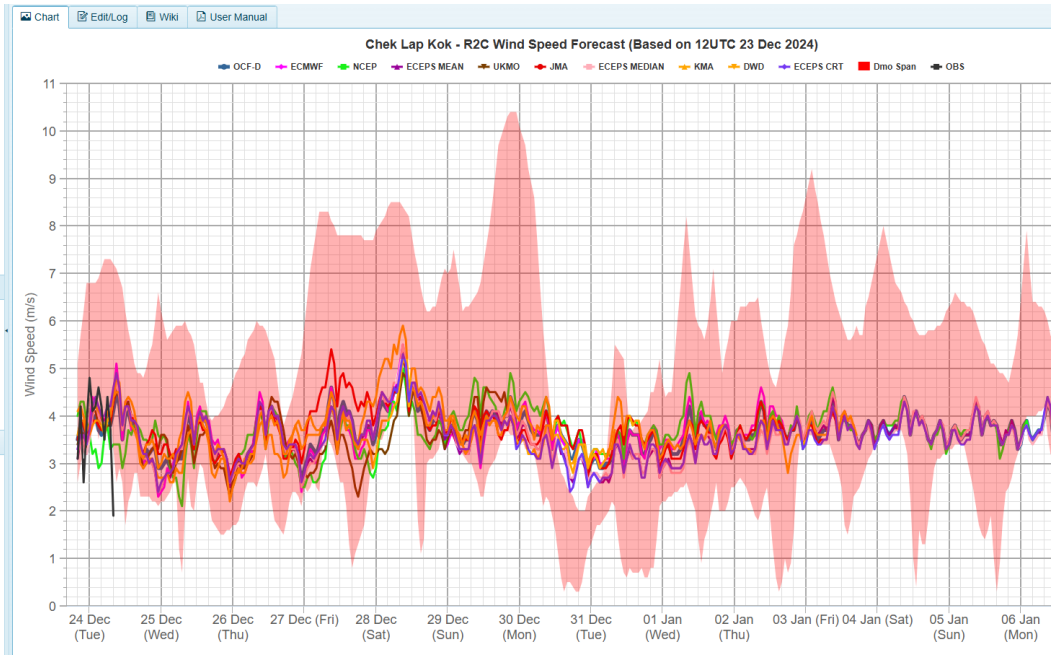
TROPICAL CYCLONE FORECAST FOR WINDS AT HKIA

Climatology



Objective Consensus Forecast (OCF)

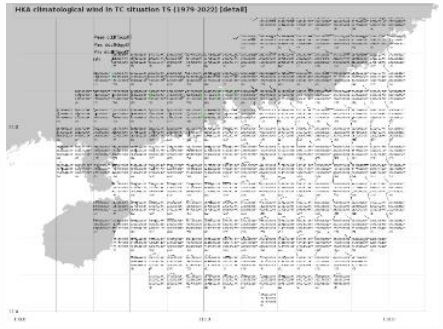




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DATA



1998-2022 (25yr)

Hourly METAR Wind, Gust & QNH

Climatological Mean Wind (1979-2018)

(Interpolated) Hourly Best Track Position, Intensity & Wind Radii

OCF Wind

AI

1998-2022 (25yr)
Wind Radii: 2004-2022 (19yr)

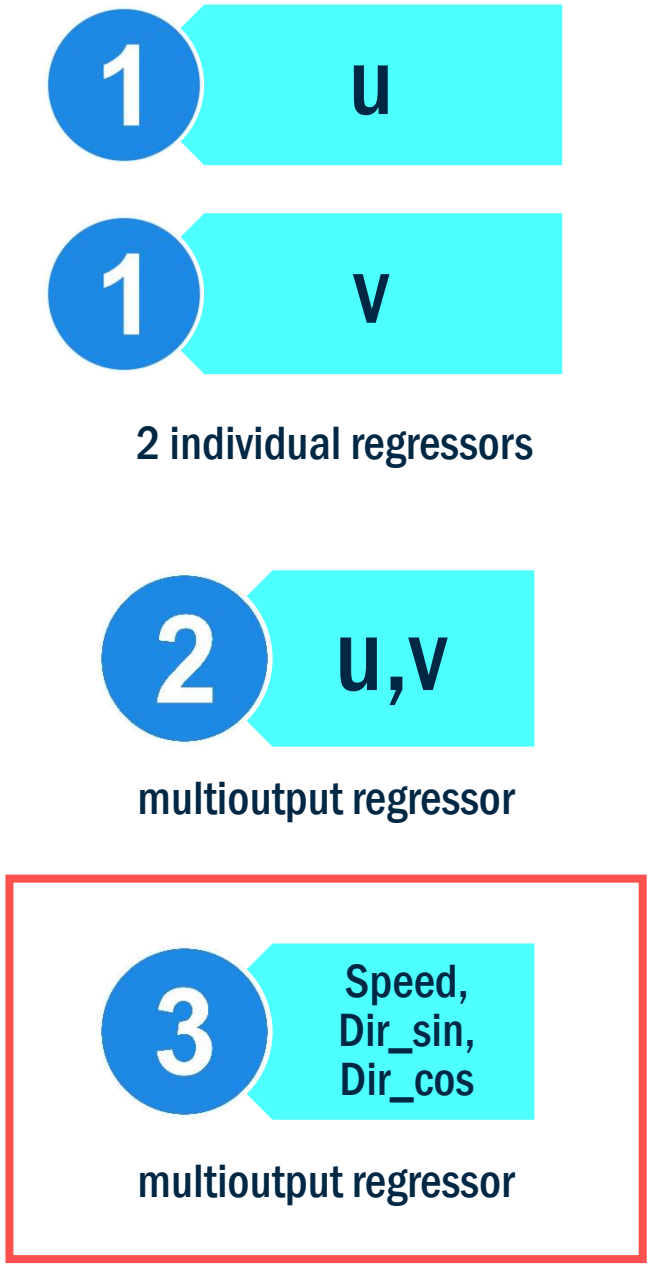
2013-2022 (10yr)

METHODOLOGY

CHOOSING THE "BEST" MODEL

- Predicting u and v would be the primarily interest
- Operational concern would focus more on the speed forecast

- Speed
  - Mean Squared Error (MSE)
  - Mean Absolute Error (MAE)
  - R-square



METHODOLOGY

WHICH AI MODEL WORKS BETTER?

Speed	XGBoost	ElasticNet	Decision Tree	Random Forest	Climate (mean)	Climate (max)	Climate (min)	OCF (Leadtime 12-23 hours)	OCF (Leadtime 24-35 hours)	OCF (Leadtime 36-47 hours)
Mean Squared Error (MSE)	19.02	20.35	35.23	19.72	30.31	187.46	99.75	21.04	23.54	28.23
Mean Absolute Error (MAE)	3.41	3.56	4.64	3.49	4.33	10.02	8.40	3.53	3.73	4.05
R-square	0.48	0.45	0.04	0.46	0.18	-4.07	-1.70	0.43	0.36	0.24

Direction	XGBoost	ElasticNet	Decision Tree	Random Forest	Climate (mean)	Climate (max)	Climate (min)	OCF (Leadtime 12-23 hours)	OCF (Leadtime 24-35 hours)	OCF (Leadtime 36-47 hours)
Root Mean Squared Error (RMSE)	31.64	32.49	58.52	34.50	33.14	80.77	69.06	37.87	47.48	51.83

METHODOLOGY

MODEL FEATURES CONSIDERED

Season	Month (cyclical)
TC Position	Latitude
	Longitude
TC Intensity	Max 10-minute Sustained Wind Speed
	Min SLP
TC Structure	F6/F8/F10/F12 wind radii
	VHHH QNH

Wind forecast Guidance	OCF HKIA Wind Speed
	OCF HKA Wind Direction (sin/cos)
	Climatological HKIA Mean Wind Speed depending on TC location and intensity
	Climatological HKIA Mean Wind Direction (sin/cos) depending on TC location and intensity
TC forecast (location and intensity)	Next 12h Forward Speed
	Next 12h Moving Direction (sin/cos)
	Past & Next 3/6/9/12/15/18/24h TC Lat & Lon
	Past & Next 3/6/9/12/15/18/24h TC Intensity (Max 10-minute Sustained Wind Speed)

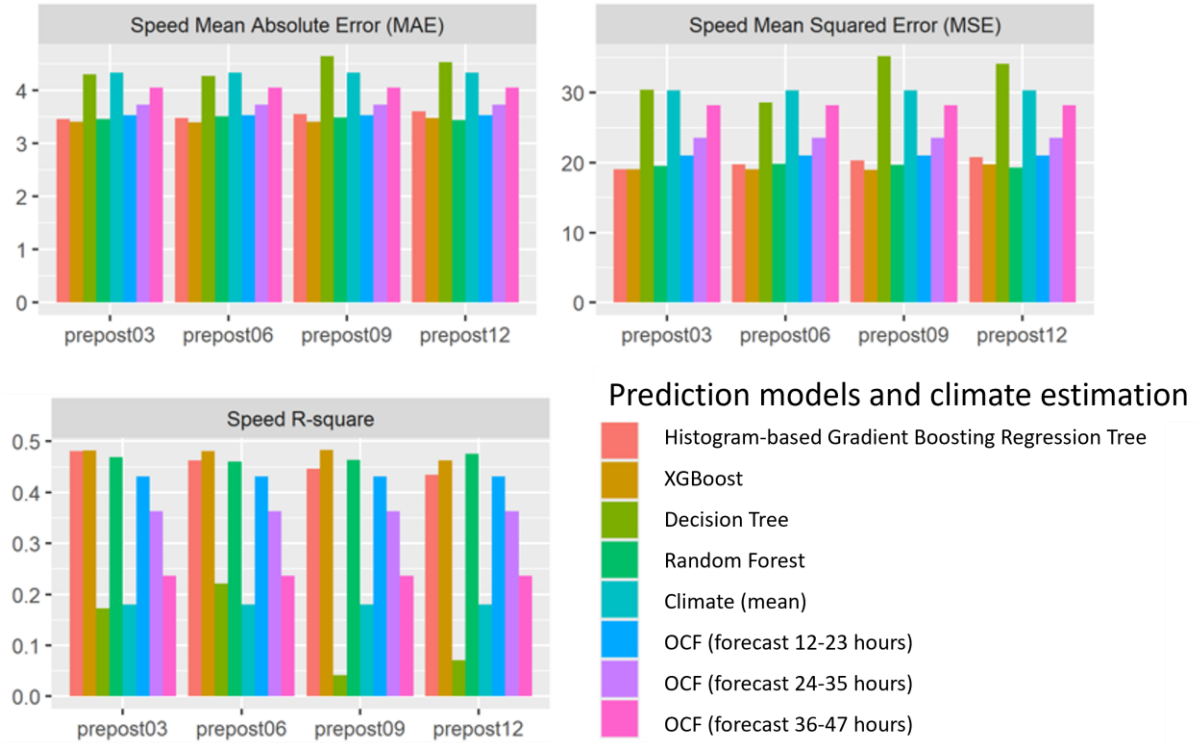
RESULTS

INTERMEDIATE FORECAST (T+0)

- Interpolated Best Track Position & Intensity to utilise hourly METAR data
- Improve speed forecast accuracy
- Past and Next 3/**6/9**/12/15/18/24h Position & Intensity

Optimal!

Speed	XGBoost (default)	XGBoost (Optuna)
Mean Squared Error (MSE)	19.02	17.48
Mean Absolute Error (MAE)	3.41	3.24
R-square	0.48	0.53

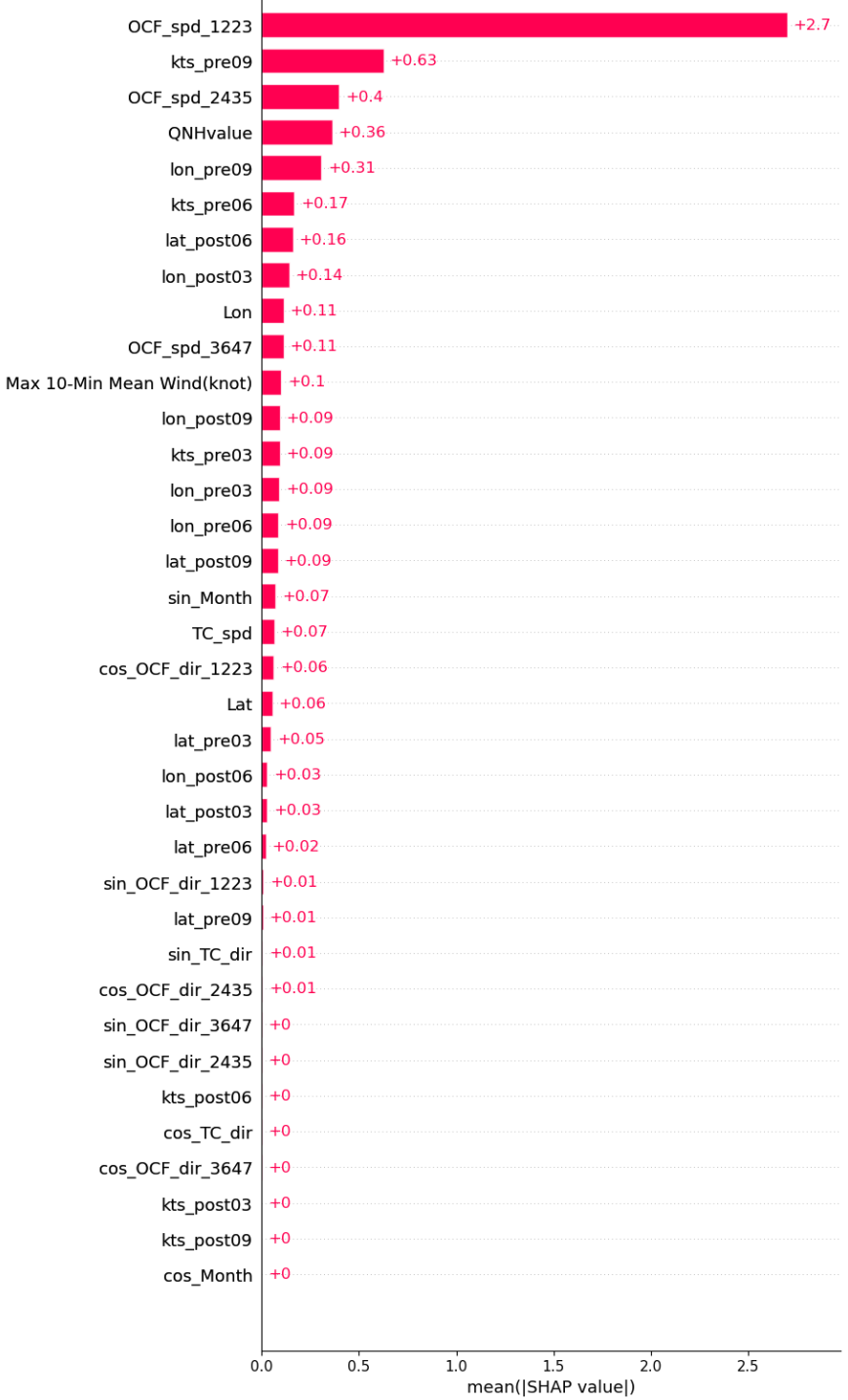


RESULTS

INTERMEDIATE FORECAST (T+0)

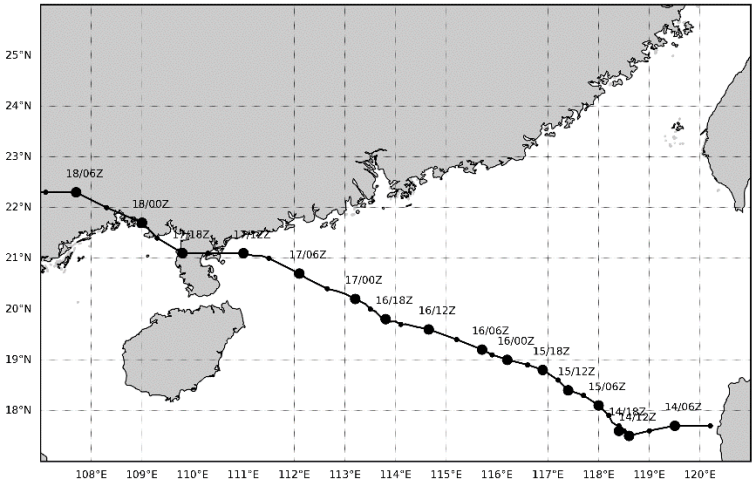
Speed	No wind radii	F6/8/10/12 radii in 4 quadrants	Max F6/8/10/12 radii
Mean Squared Error (MSE)	17.48	17.28	17.41
Mean Absolute Error (MAE)	3.24	3.22	3.24
R-square	0.52	0.53	0.53

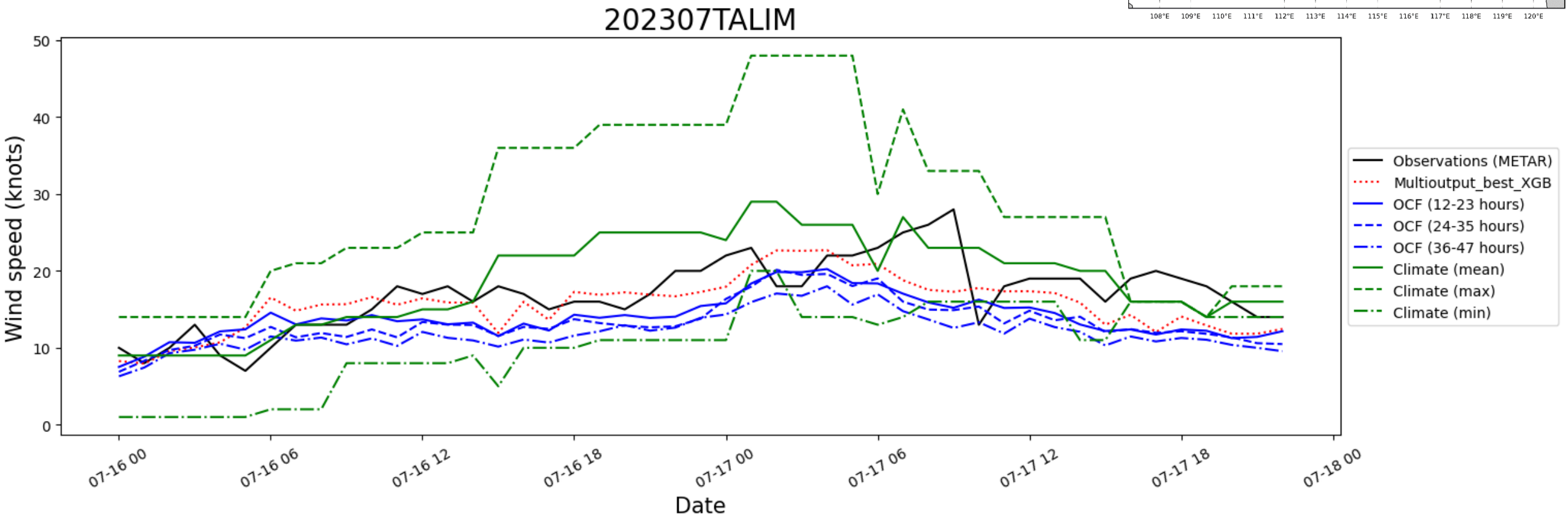
Direction	No wind radii	F6/8/10/12 radii in 4 quadrants	Max F6/8/10/12 radii
Root Mean Squared Error (RMSE)	32.82	34.63	33.33



EXAMPLE

INTERMEDIATE FORECAST (T+0)



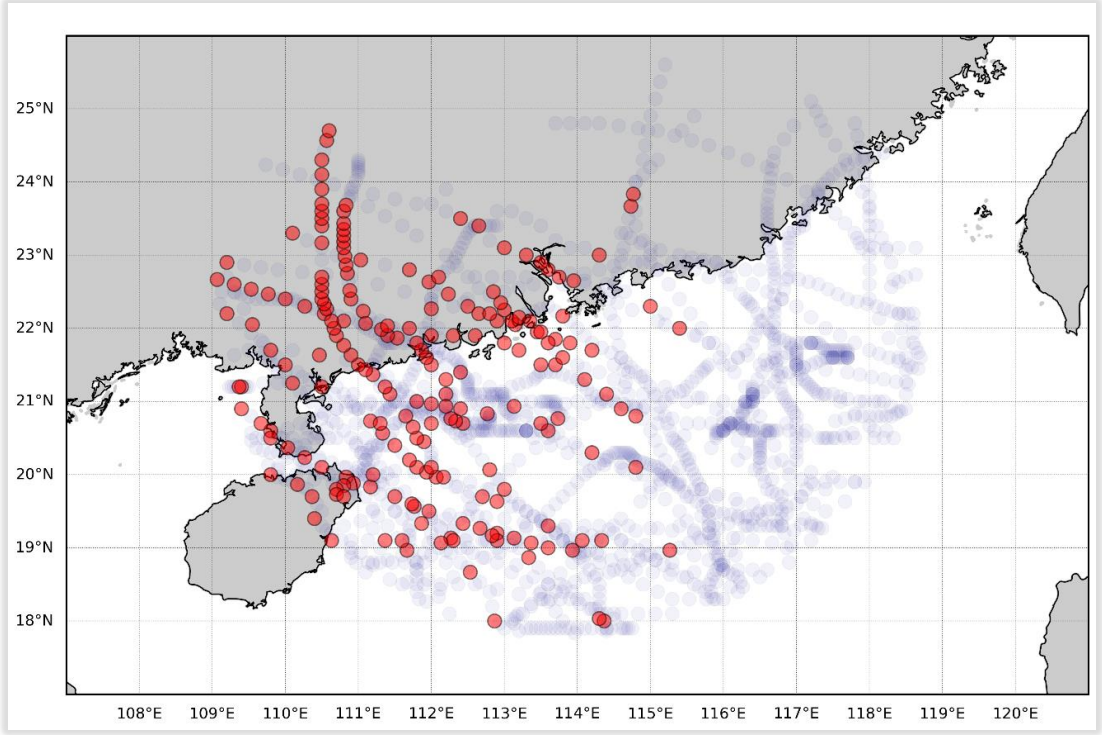


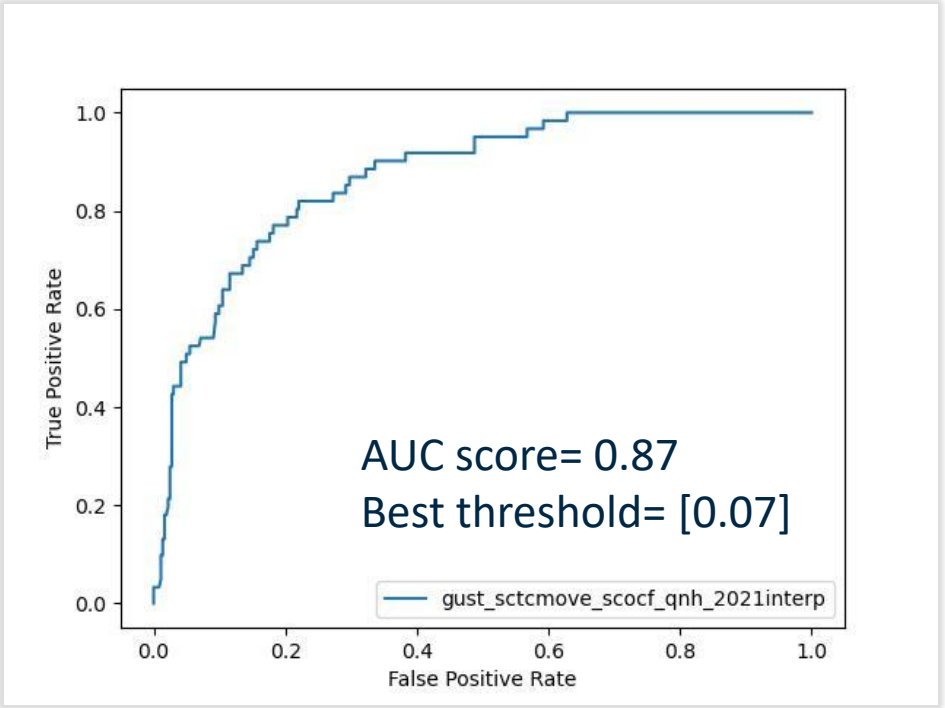
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RESULTS

INTERMEDIATE GUST PROBABILITY FORECAST (T+0)



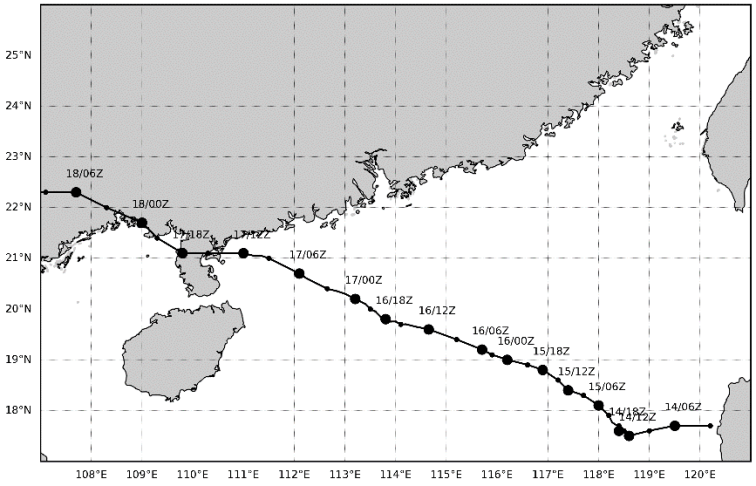


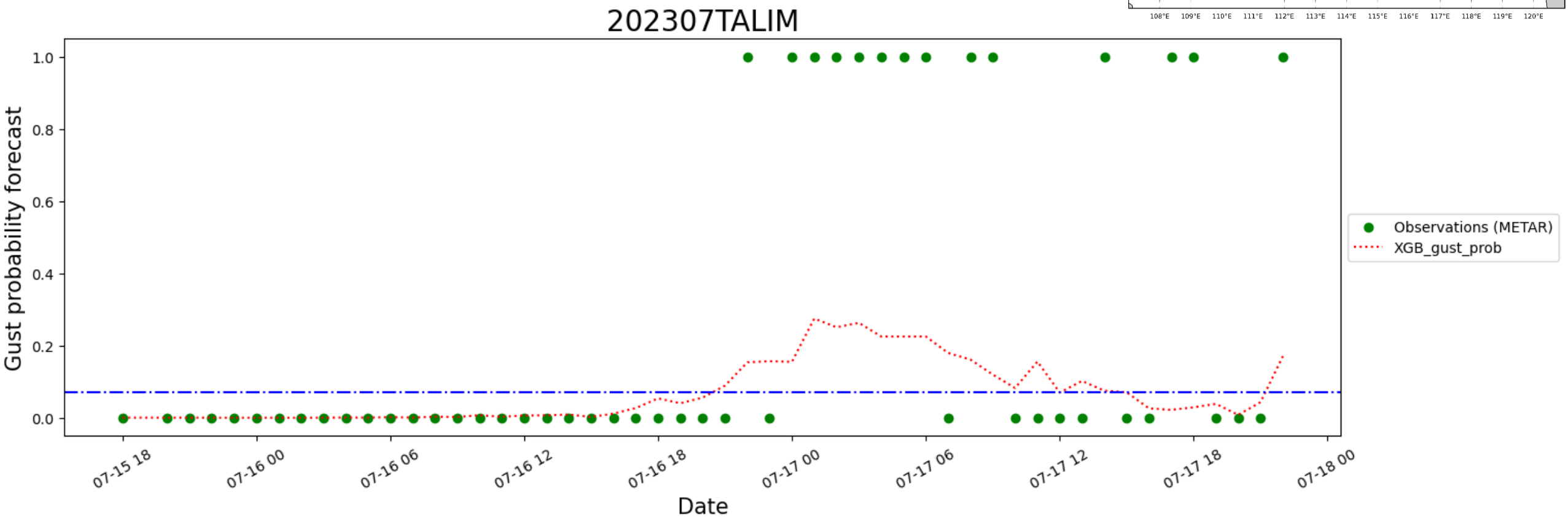
POD=0.79
FAR=0.61
CSI=0.35
COUNT=424

	No gust forecast	Gust forecast
No gusts observed	287	76
Gusts observed	13	48

RESULTS

INTERMEDIATE GUST PROBABILITY FORECAST (T+0)





RESULTS

SHORT-TERM FORECAST (T+1 TO T+12 HOURS)

Speed	XGBoost	OCF with 12-23 hour lead-time	OCF with 24-35 hour lead-time	OCF with 35-47 hour lead-time
Mean Squared Error (MSE)	15.96	22.72	26.38	31.94
Mean Absolute Error (MAE)	2.99	3.63	3.83	3.96
R-square	0.58	0.40	0.34	0.27

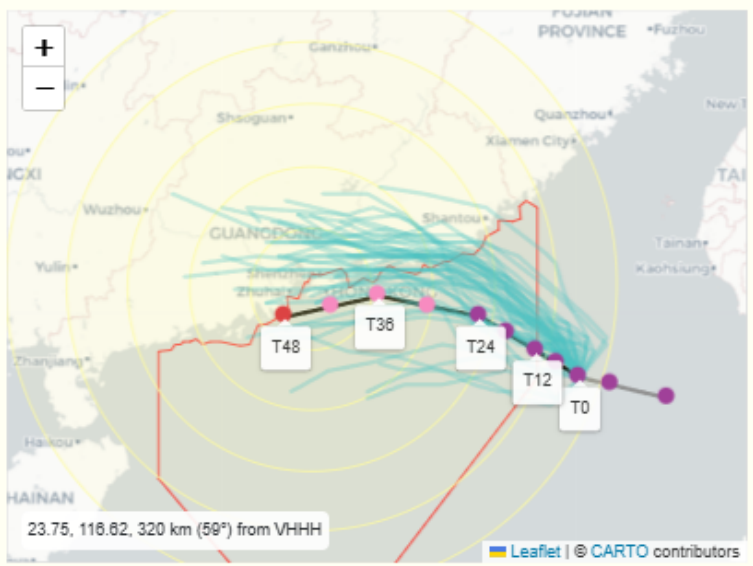
RESULTS

EXTENDED FORECAST (T+1 TO T+36 HOURS)

Speed	XGBoost as 3 separate models (T+1 to T+12 hours, T+13 to T+24 hours, T+25 to T+36 hours)	XGBoost as one model (T+1 to T+36 hours)	OCF (T+1 to T+36 hours)
Mean Squared Error (MSE)	23.80	24.55	28.74
Mean Absolute Error (MAE)	3.51	3.51	3.97
R-square	0.44	0.43	0.33

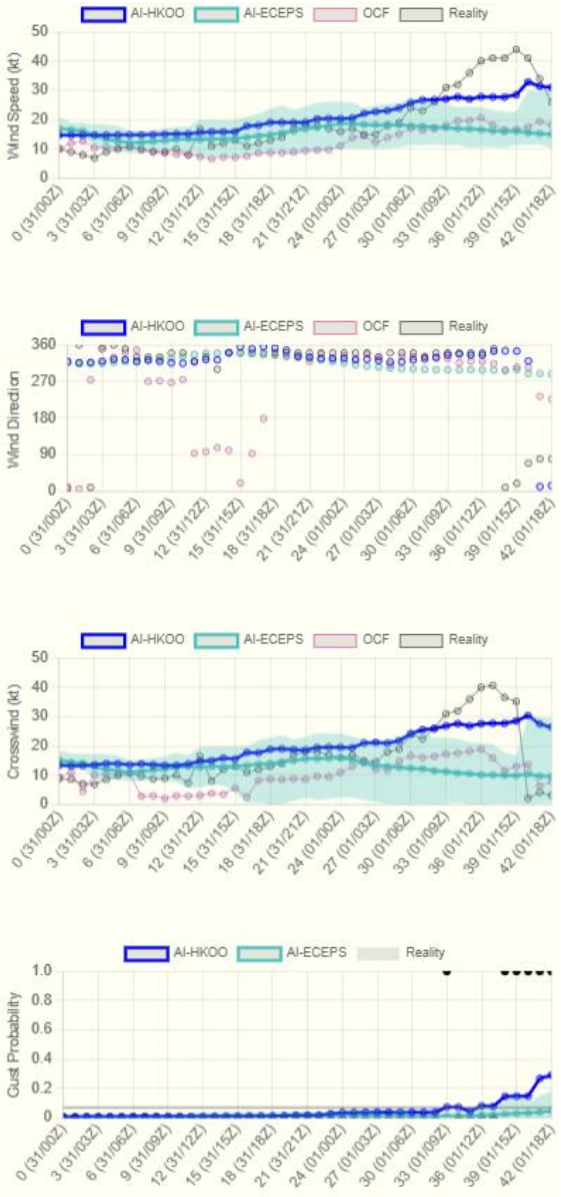
CASE STUDY

TC SAOLA (2023)



Time now?	2023083100			
T-12	20.70	119.60	125	SuperT
T-6	20.90	118.70	115	SuperT
T+0	21.00	118.20	115	SuperT
T+6	21.20	117.85	111.25	SuperT
T+12	21.40	117.50	107.5	SuperT
T+18	21.65	117.05	103.75	SuperT
T+24	21.90	116.60	100	SuperT
T+30	22.05	115.80	95	ST
T+36	22.20	115.00	90	ST
T+42	22.05	114.25	85	ST
T+48	21.90	113.50	80	TY

Calculate and Wait



DISCUSSIONS

- The ability to capture **non-linear relationships**.
- **Improved accuracy** in predicting wind speed during TCs.
- The potential to quantify forecast **uncertainty** and provide **scenario-based guidance** by adjusting TC track and/or intensity deviations.

- Future work:
  - including wind direction forecast
  - integrating these models into operational workflows
  - exploring their applications in other high-impact weather scenarios (windshear, low level turbulence, etc.)
  - to incorporate nearby airport observations and more pressure pattern metrics as model features

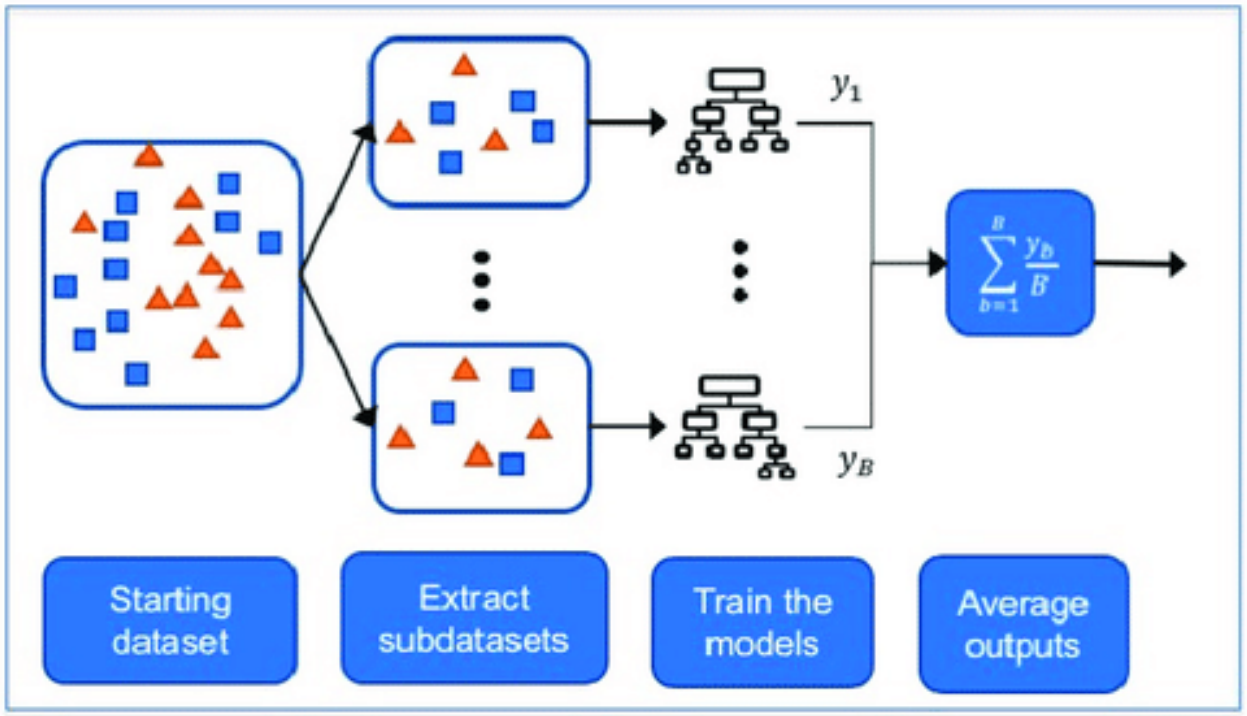
Thank you for listening!

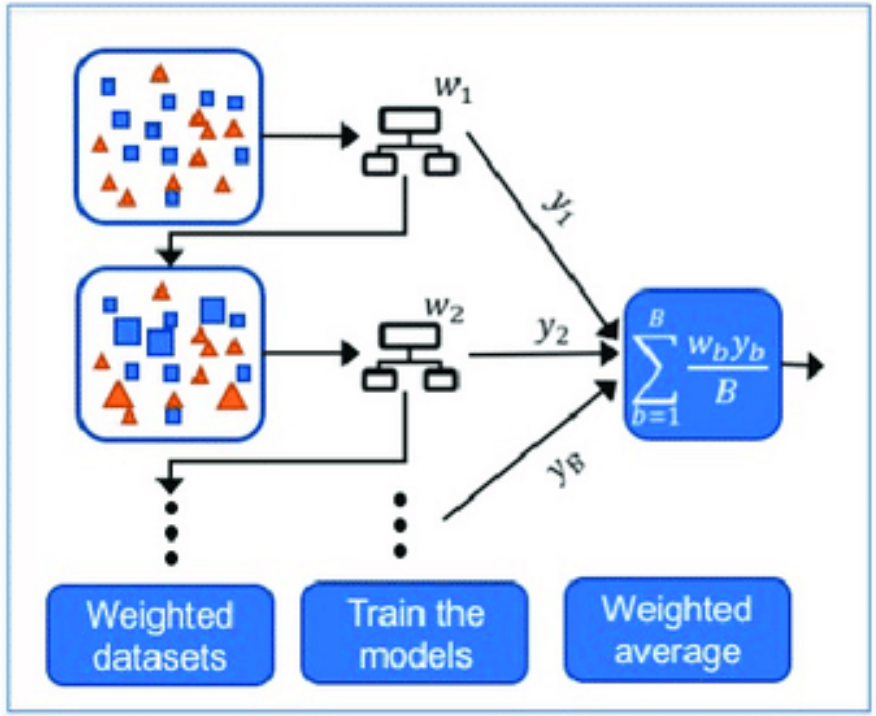
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BAGGING AND BOOSTING

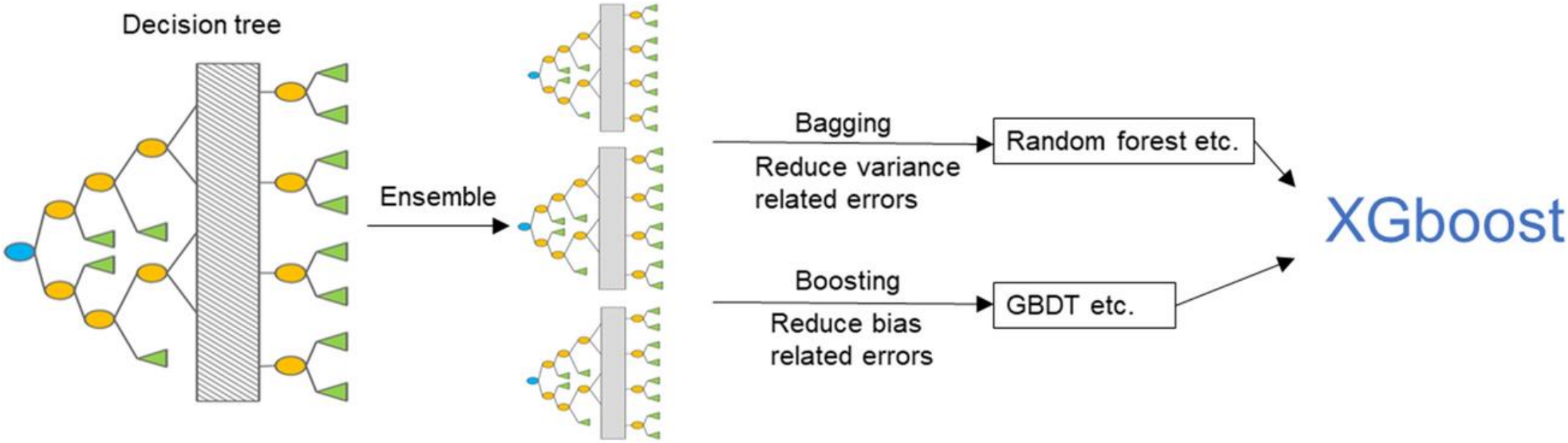




Description of bagging (left) and boosting (right) approaches. Larger squares and triangles illustrate how the instances might receive different weights when training the learners in boosting procedures.

Seccia, Ruggiero, et al. "Machine learning use for prognostic purposes in multiple sclerosis." Life 11.2 (2021): 122.

XGBOOST



Schematic representation of the XGBoost model. XGBoost, extreme gradient boosting; GBDT, gradient boosting decision tree.

Jiang, Jiuzhou, et al. "Predictive model for the 5-year survival status of osteosarcoma patients based on the SEER database and XGBoost algorithm." Scientific reports 11.1 (2021): 1-9.